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WADC TECHNICAL REPORT 52-283
PART 4

AIR PERMEABILITY OF PARACHUTE CLOTHS

H. W. S. LAVIER

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY

FEBRUARY 1955

WRIGHT AIR DEVELOPMENT CENTER

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FEBRUARY 1955

MATERIALS LABORATORY
CONTRACT No. AF 33(038)-15624
PROJECT No. 7320

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
300 - 20 May 1955

FOREWORD

This report was prepared by the Engineering Experiment Station of the Georgia Institute of Technology under Contract No. AF 33(038)-15624. The contract was initiated under Project No. 7320, "Air Force Textile Materials," Task No. 73201, "Textile Materials for Parachutes," formerly RDO No. 612-12, "Textiles for High Speed Parachutes," and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center with Mr. J. H. Ross acting as project engineer.

Mr. W. C. Boteler, Research Assistant, capably assisted the author in completing the work reported here. Dr. Fred Bellinger and Dr. Thomas W. Jackson of Engineering Experiment Station staff provided valuable counsel and offered many pertinent suggestions.

Professor G. B. Fletcher of the Textile Engineering School and Mr. Hamilton J. Bickford of Cheney Brothers Manufacturing Company provided valuable counsel on weaving technicalities.

ABSTRACT

The high-pressure air permeability of selected nylon, Orlon, and Dacron parachute-type fabrics was determined using a 16-square-inch sample. The Georgia Tech high-pressure permeometer used in this program permitted testing the fabric samples at pressure differentials across the cloth equivalent to 1500 inches of water. The selected cloths are described in Table I and include experimental cloths woven in the Laboratories of the Georgia Institute of Technology.

Air-permeability data for the selected fabrics are presented here in graphical and tabular form as volumetric flow (cubic feet per minute) and effective porosity versus the static pressure differential across the cloth.

The selected fabrics were chosen to demonstrate the effect on high-pressure air permeability resulting from variation of the number of ends and picks per inch, weave patterns, and material. Also, the effect on high-pressure permeability, due to variation of temperature and absolute humidity, was investigated.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER :

M. R. Whitmore

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

I. INTRODUCTION

A. Statement of the Problem

The work presented here is a continuation of the study reported in USAF Technical Report No. WADC 52-283, Parts 1, 2, and 3. These studies are to determine the air permeability of selected nylon, Orlon, and Dacron parachute-type fabrics under conditions of high-pressure differentials across the fabric samples. Conditions approximating the rapid or shock loading of the actual parachute cloth were reproduced. The effect on air permeability, due to variation of yarn denier, weave, nylon, Orlon, or Dacron material, constitutes the objective of the subject research.

B. Definition of Terms

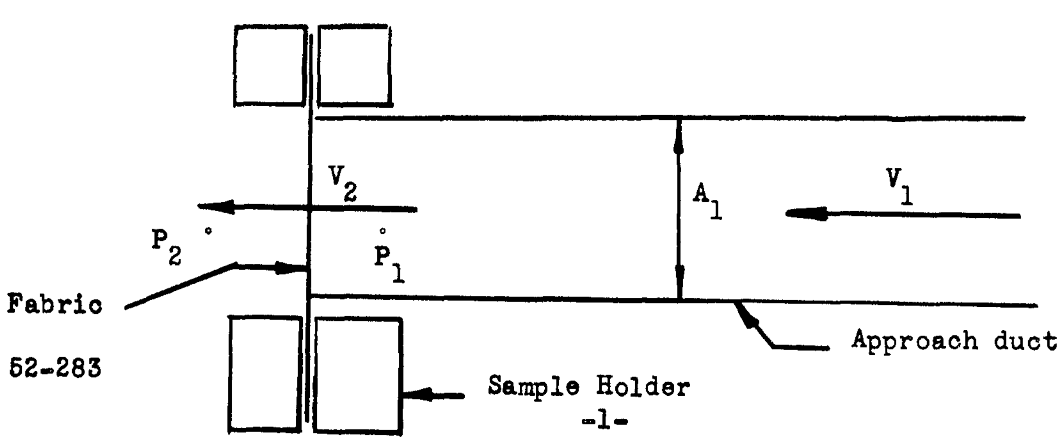
In this report the following definitions of permeability and porosity will be adhered to:

Permeability: the mass rate of flow or the volume rate of air flow per unit area of the cloth.

Porosity: the ratio of projected void or interstitial area to total area of the cloth sample expressed in percentage (%).

Effective Porosity: the ratio of the velocity of the air upstream of the cloth to the average velocity of flow through cloth interstices.

The illustrative sketch below and the symbols used will implement these definitions. Subscripts 1 and 2 indicate, respectively, flow properties upstream and downstream relative to the fabric sample.



$$\text{Permeability} = \rho_1 V_1 = G(\text{lbs/sec - ft}^2)$$

$$\text{or} = V_1 A_1 / A_1 = Q(\text{ft}^3\text{/sec - ft}^2)$$

$$\text{Porosity} = \frac{A_{void}}{A_{total}} \times 100, \text{ per cent}$$

$$\text{Effective Porosity} = \frac{V_1}{V_2} \quad \text{(dimensionless)}$$

II. LITERATURE SURVEY

All available sources of literature are continually searched for information pertinent to the air permeability of parachute fabrics including methods and equipment for conducting air-permeability studies.

Few articles have been found concerning this particular subject. In the field of high-pressure permeability research, a high-pressure permeometer was described by Carling and Leigh in reference 1. Such literature that has been useful in this work has been prepared at Georgia Tech and also by Fabric Research Laboratory, Inc., during the course of the subject research. Particularly in the range of high-pressures such as that equivalent to 1500 inches of water there have been found no pertinent articles.

III. APPARATUS

A. Georgia Tech High-Pressure Permeometer

The Georgia Tech high-pressure permeometer was specially designed for use in the subject research. This machine was designed to provide a pressure differential across the fabric sample up to that equivalent to 1500 inches of water. In principle, by use of an orifice meter, pressure-sensing elements, thermocouples, and other instrumentation, the properties of the air flow through the 16-square-inch cloth sample are simultaneously recorded. From such data the air permeability of the fabric is computed.

A large 12 by 13-inch Worthington air compressor driven by a Westinghouse 75-hp electric motor provides compressed air up to a maximum of 125-psi pressure. The air is hot due to compression and is cooled in a Worthington water-cooled aftercooler before passing through a C. D. Kemp single-tower adsorption dryer. The compressor is shown in Figure 1, and the dryer is presented in Figure 2.

After drying, the air is stored in a large 1000-cubic-foot reservoir. Air pressure for the test is regulated to the desired value by a large pressure regulator and a 100-cubic-foot surge tank. The storage tank, pressure regulator valve, and surge tank are shown in Figure 3.

The pressure supply system of the Georgia Tech High-pressure air permeometer terminates at a simple, quick-acting, shut-off valve. The high-pressure permeometer basically consists of an orifice-meter section and sample-holder adapter at the outlet end. The high-pressure permeometer and the shut-off valve are shown in Figure 4.

Air temperature at the cloth sample is regulated by two devices. Warm air test temperatures are obtained by adjusting the flow of cooling water through the Worthington aftercooler. Cold temperatures are obtained by introducing varying amounts of liquid nitrogen into the compressed air stream. Figure 5 is a schematic diagram of the Georgia Tech high-pressure permeometer. The cooling system is shown in the insert. The controls of this apparatus are shown in Figure 6. Diffusion of the injected nitrogen is obtained by passing the mixture through at least two turbulence screens located on either side of the cut-off valve.

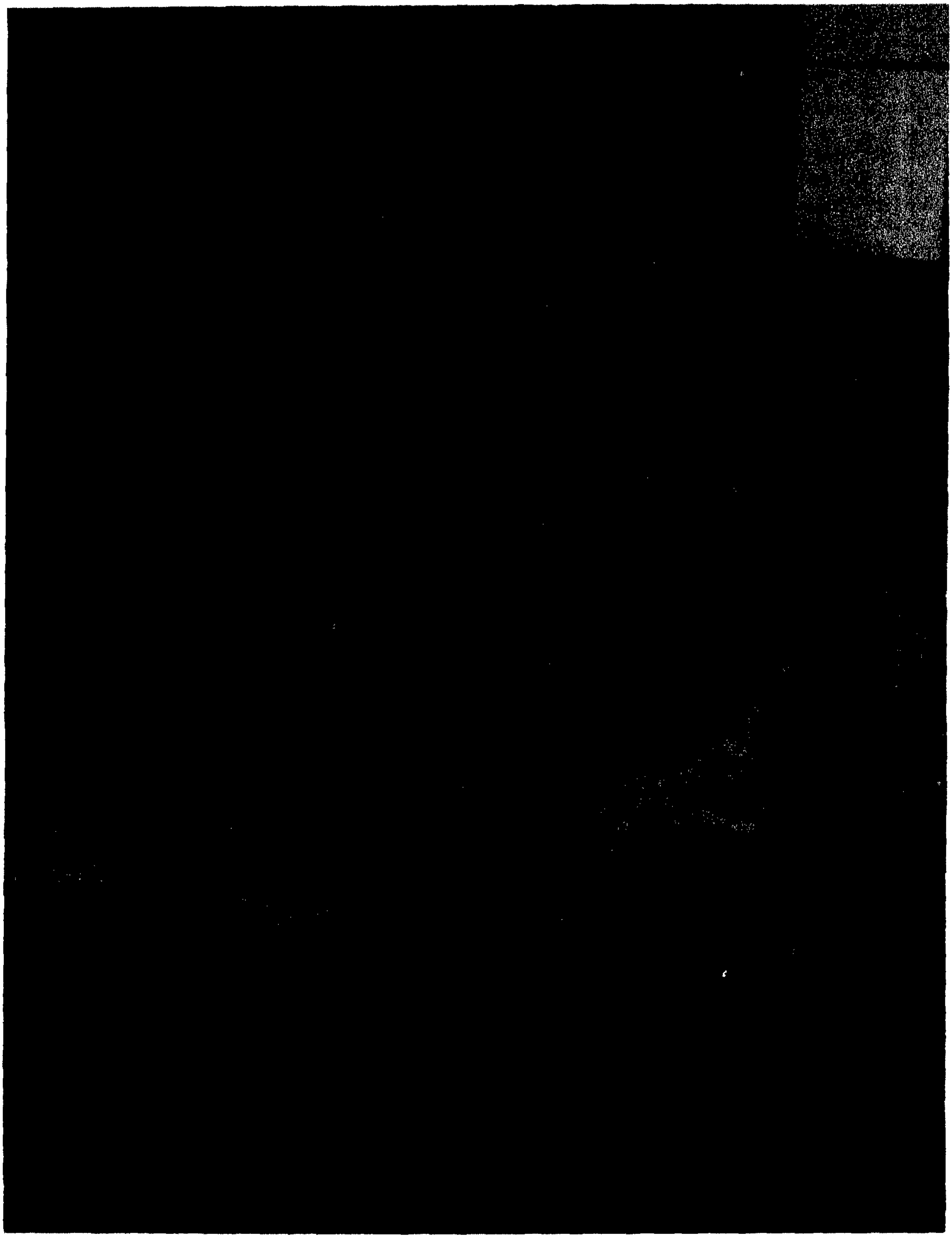


Figure 1. Worthington 12 by 13-Inch Compressor

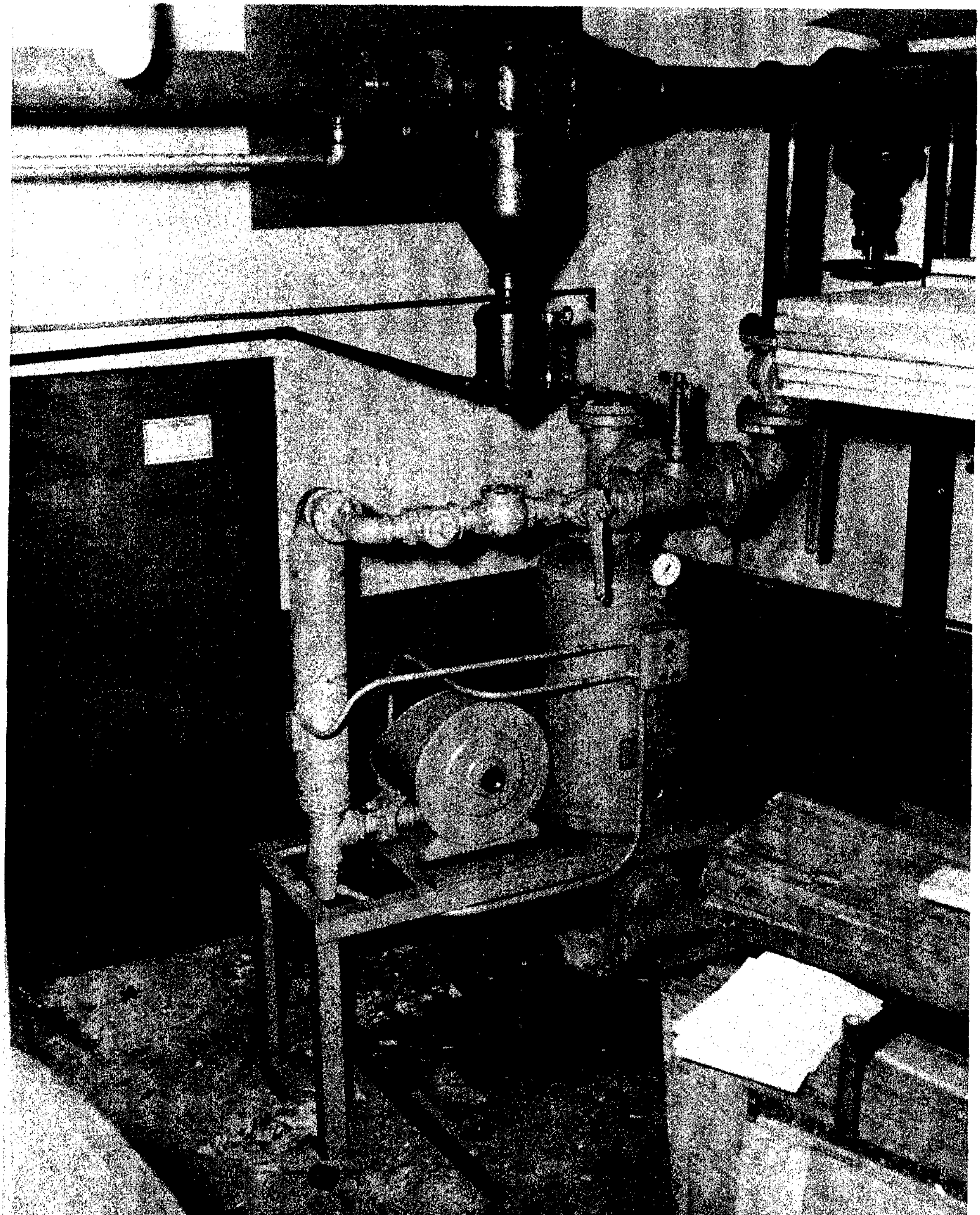


Figure 2. Kemp Adsorption Dryer.

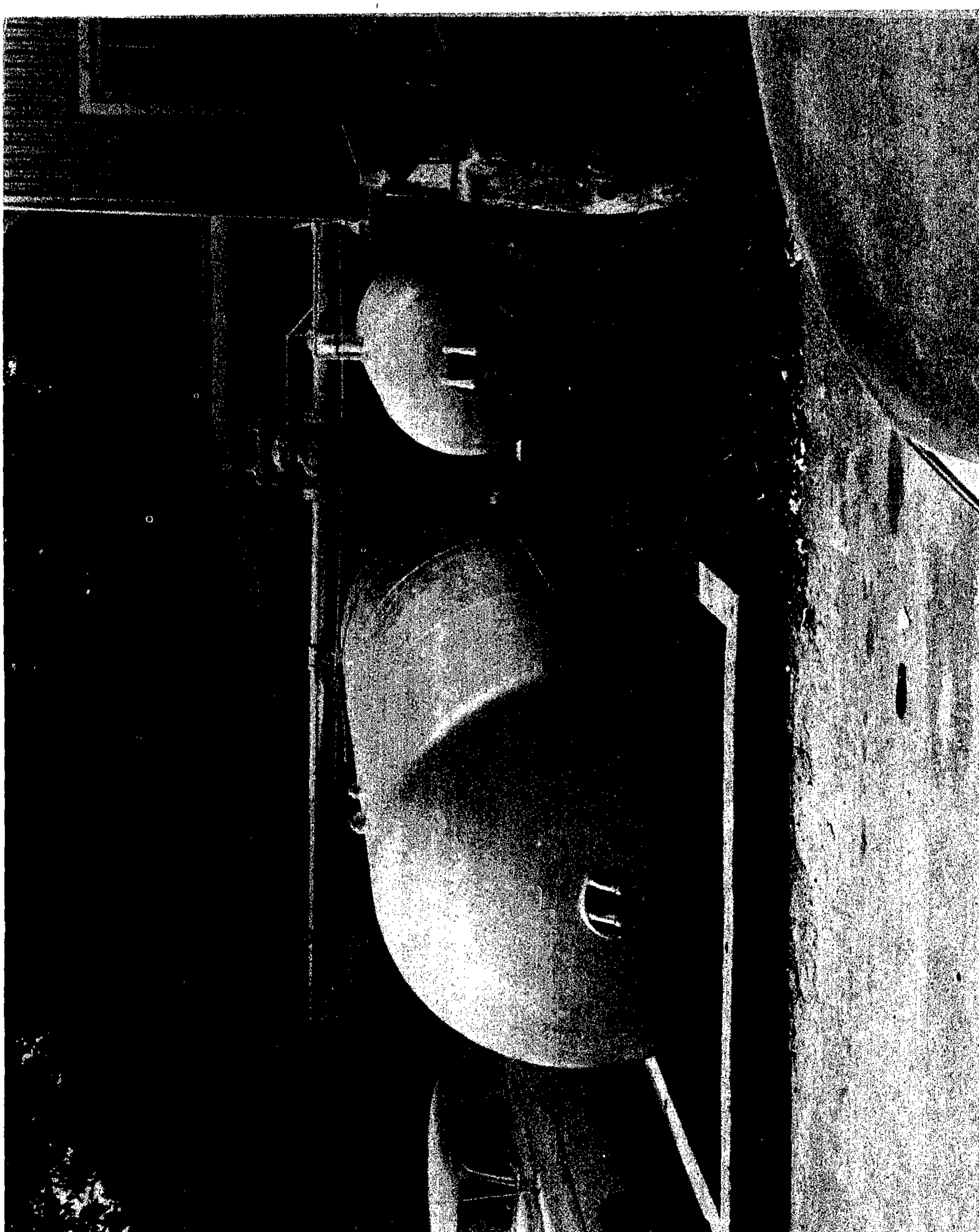


Figure 3. General View of Reservoir and Pressure Regulation System.

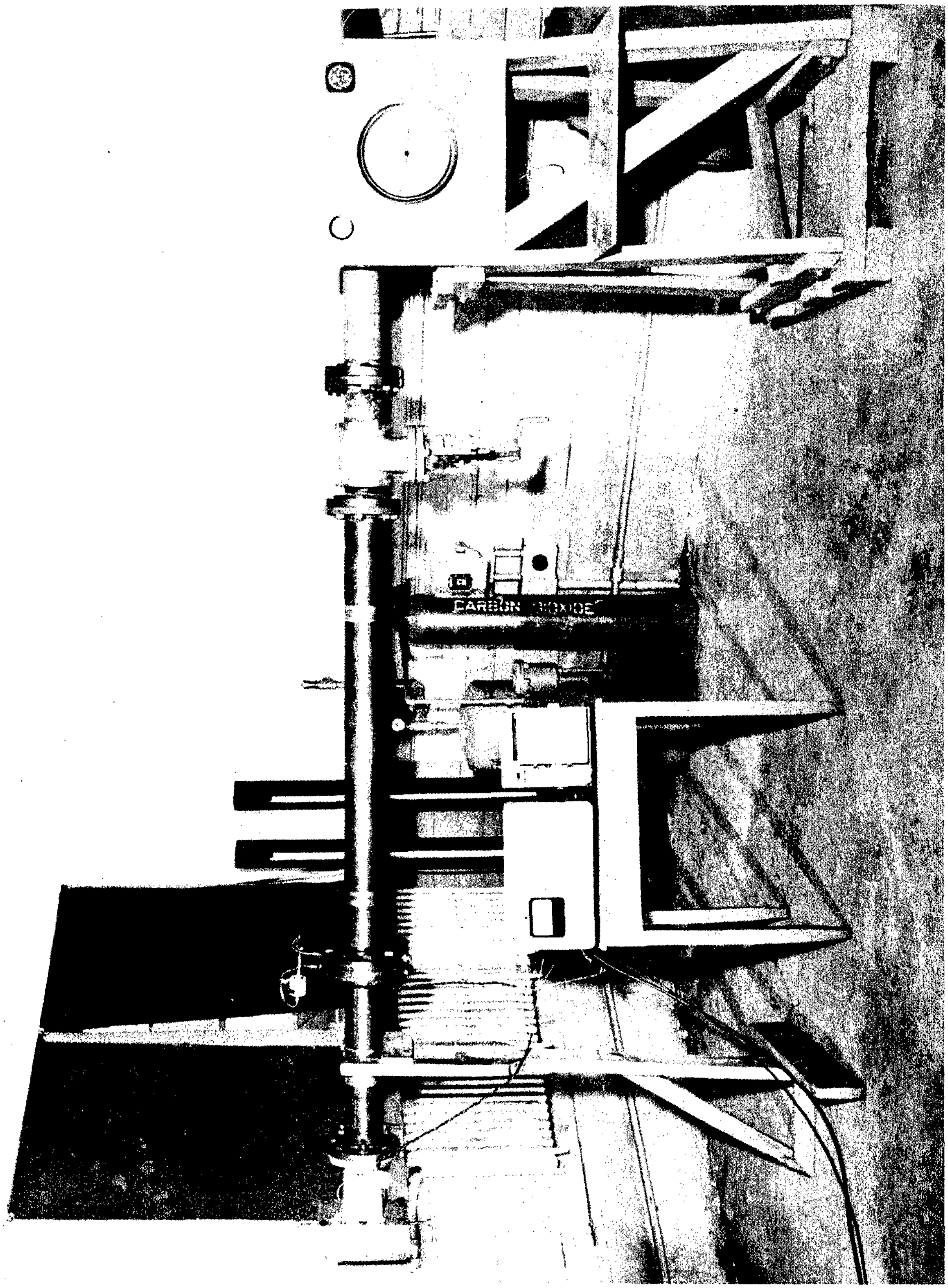


Figure 4. General View of the Georgia Tech High-Pressure Permeometer.

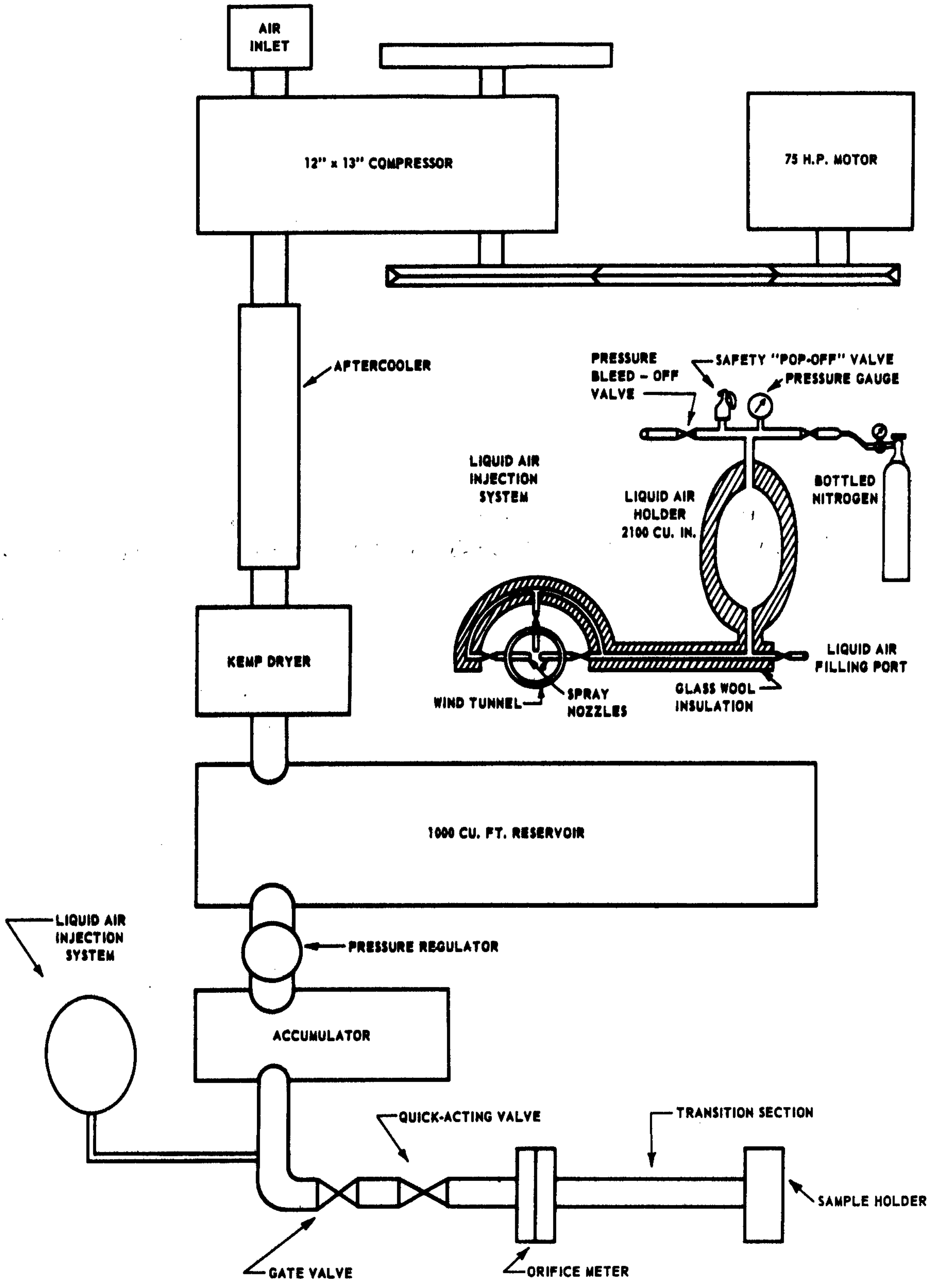


Figure 5. Schematic Diagram of the Georgia Tech High-Pressure Permeometer.

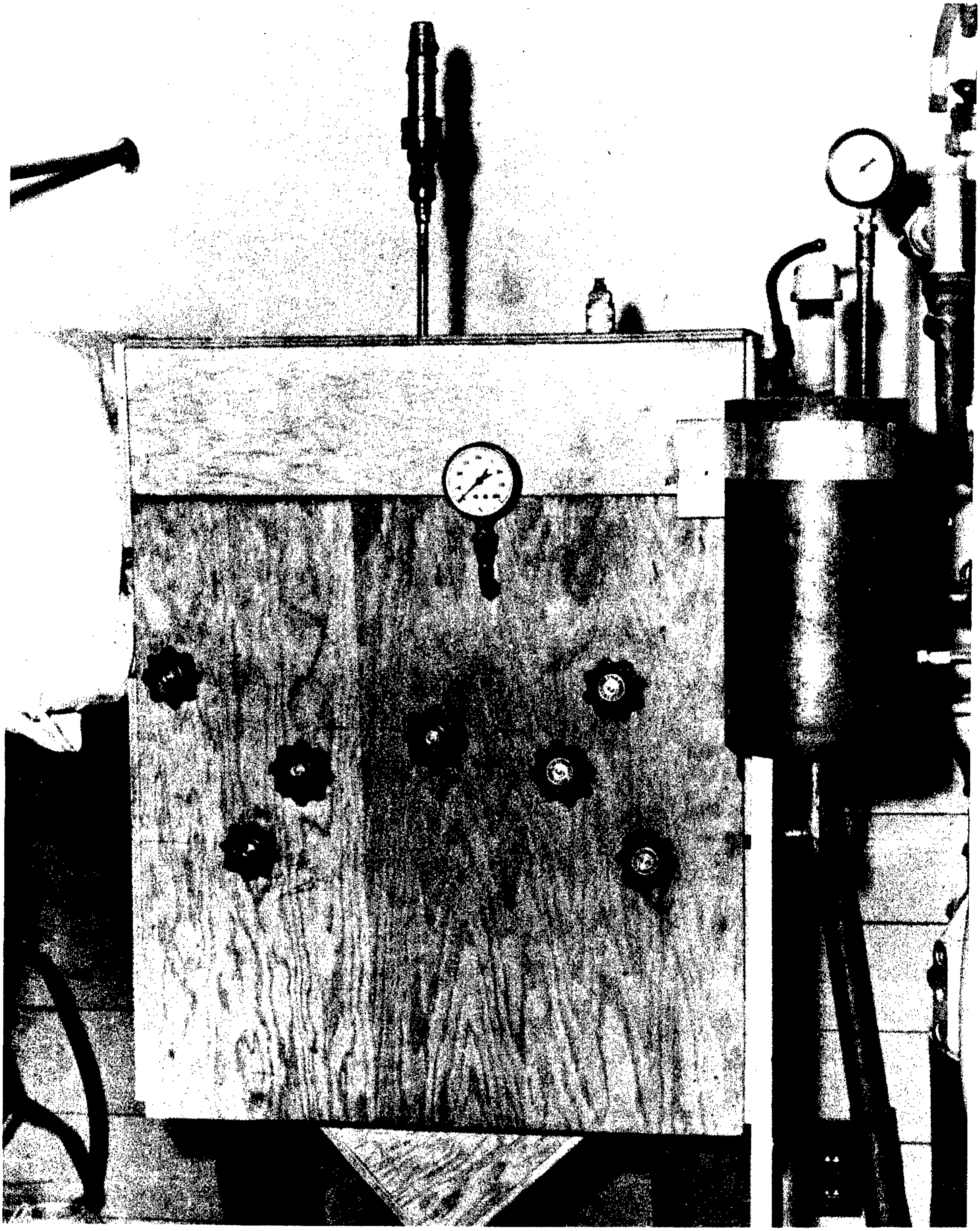


Figure 6. Cooler Controls of the Georgia Tech High-Pressure Permeometer.

B. Instrumentation

The instrumentation of this apparatus constitutes one of its major features. Fast-acting, inertia-free, electric-resistance type pressure pick-ups manufactured by Trans-Sonics, Inc., and CEC Instruments Corp. are used to indicate the magnitude and variation of air pressure in the storage tank, across the orifice meter, and across the fabric sample. The signal from these pick-ups actuates the galvanometers in a nine-channel photo-recording oscillograph manufactured by CEC Instruments Corp.

Temperatures in the storage tank, at the orifice meter, and upstream of the cloth, are indicated by simple single joint thermocouples actuating galvanometers in the oscillograph and utilizing another joint in an ice bath as a reference. A typical specimen oscillograph record is shown in Figure 7.

C. Simple Sample Holder

A simple sample holder having a 16-square-inch (4" x 4") opening is used in these tests. It consists of two plates provided with appropriate rubber-retaining seals. The fabric sample is clamped between the two 3/4-inch thick aluminum plates, and the holder is then bolted on the end of the high-pressure permeometer. Figure 8 is a general view of the Simple Sample Holder.

D. Biaxial-Tension-Measuring Sample Holder

It is desirable to measure the actual tension loads in both warp and filling directions when the fabric sample is subjected to actual air loading. A special sample holder has been designed and constructed for this purpose.

The fabric is secured by four pairs of clamp-type jaws. Each pair of jaws are connected to an external cantilever arm located on the perimeter of the sample holder. Two of these cantilevers are provided with electric resistance strain gages so mounted as to indicate by variation of electric resistance

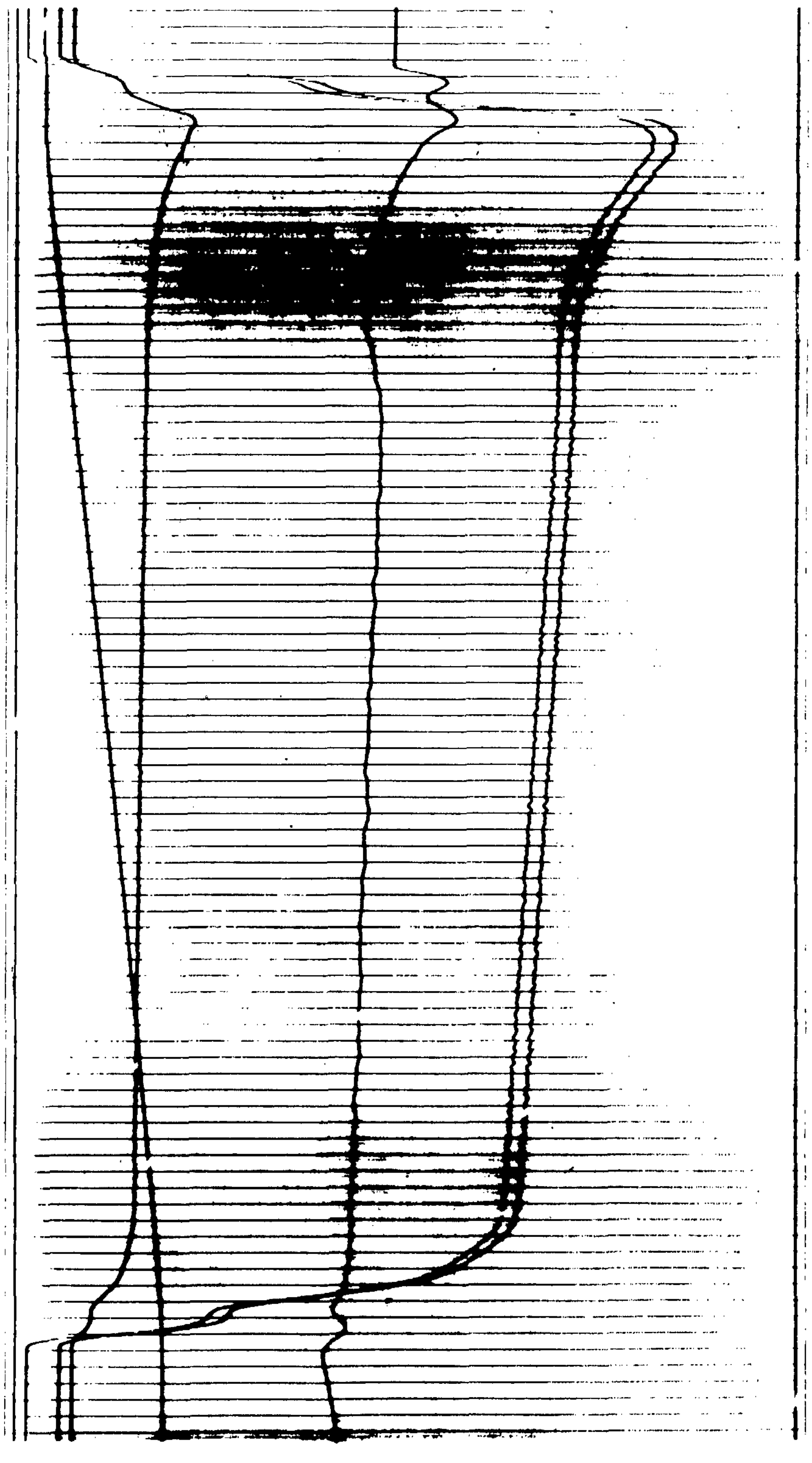


Figure 7. A Photograph of a Portion of a Typical Oscillograph Record.

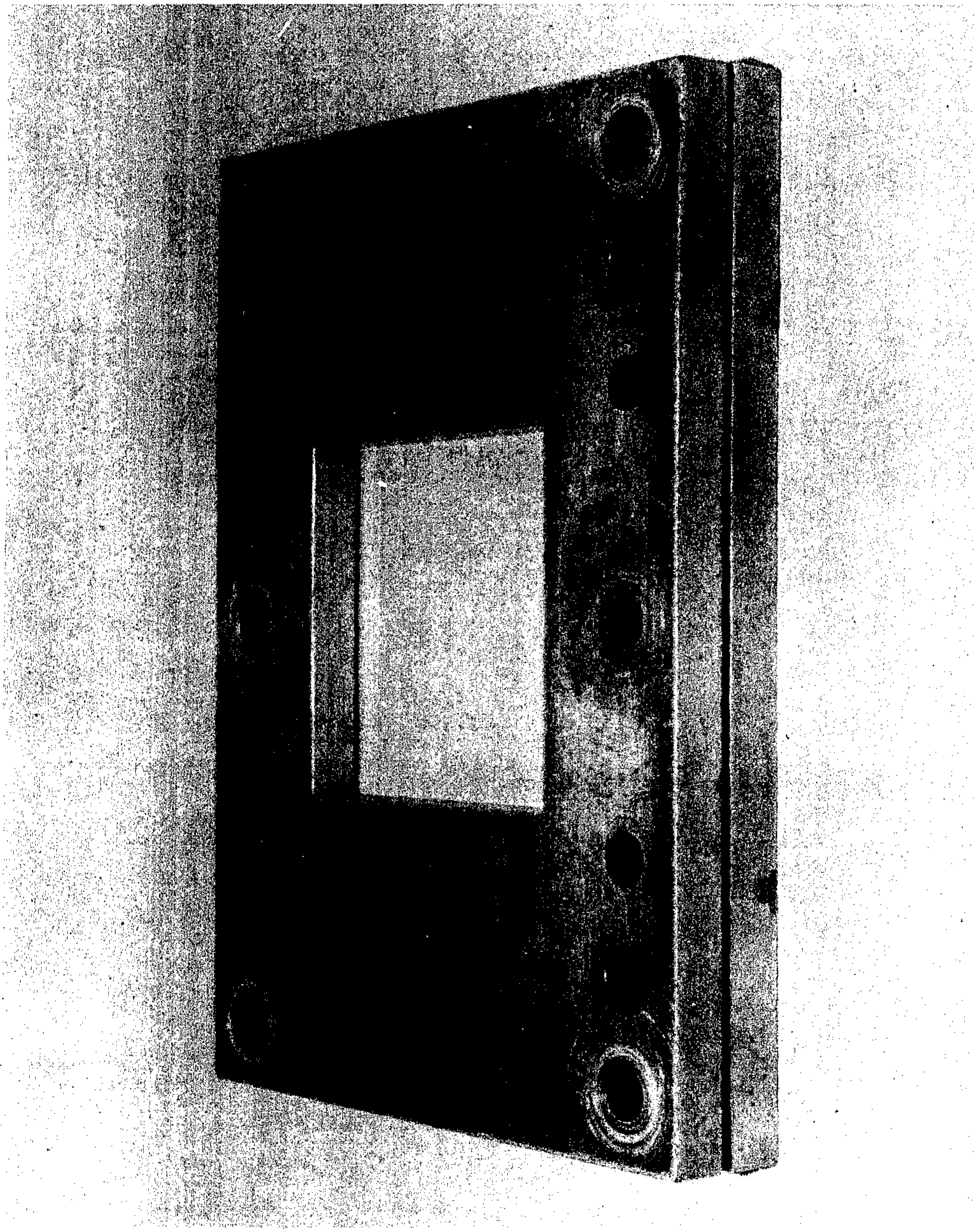


Figure 8. General View of the Simple Sample Holder.

the magnitude and variation of fabric tension loads. Figure 9 is a general view of the biaxial-tension-measuring sample holder with cover plate removed.

IV. TEST PROCEDURES AND METHOD OF HANDLING DATA

A. Selection of Cloth Samples

Phase II, the high-pressure part of the air-permeability studies, requires the testing of selected nylon, Orlon, and Dacron parachute-type fabrics under pressure conditions up to an equivalent of 1500 inches of water. Several of the high strength standard Air Force parachute fabrics were added to the list of selected fabrics and will be discussed in Part 5 of this report. Fabrics have been selected to demonstrate the effect of variation of weave patterns, number of ends and picks per inch, denier of yarns, and material. Table I lists the selected fabrics and gives the basic fabric properties.

A statistical study was conducted to determine the number of samples and their position on the yardage from which each cloth sample was taken (2). It was concluded that nine samples should be taken at random throughout the length of the fabric to be tested. The samples should be located one-third of the way in from the selvage. This procedure for selecting test samples has been used in the previous research.

B. Sample Mounting Procedure

In the simple sample holder, it is important that the sample be cut large enough to permit the secure clamping of the sample between the two halves of the sample holder. The cloth is oriented so that warp and filling threads are mutually perpendicular to the edges of the aperture. The cloth is drawn taut, by use of the fingers, eliminating any slack. After mounting the fabric sample, the sample holder is bolted securely to the end of the permeometer.

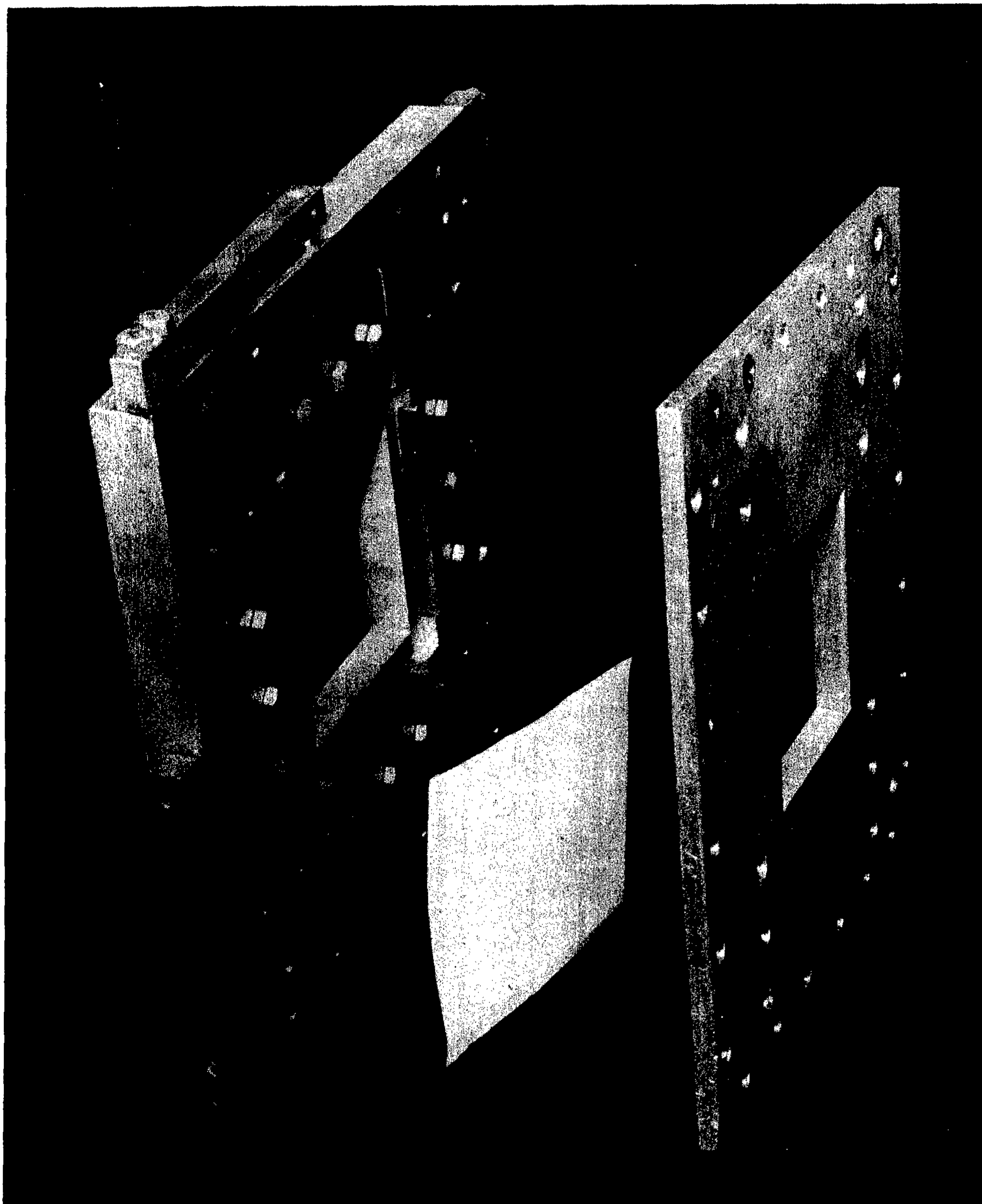


Figure 9. General View of the Biaxial-Tension-Measuring Sample Holder.

A similar technique is used in the case of the biaxial-tension-measuring sample holder. Again the sample is cut large enough so that each pair of jaws will fully engage the cloth. The sample is secured between two jaws located at 90 degrees to each other, and then drawn finger-tight as each of the remaining two clamps is secured.

Considerable conjecture has been raised from time to time concerning the magnitude of initial fabric tautness and the necessity for measuring this initial state. It is recognized by the author that this tautness is very small compared to the subsequent cloth tension during the high-pressure permeometer test. Neglecting this amount does not in any way invalidate the important high-pressure data. The effort of the experimenters has been to achieve one of the essentials of good research technique; that of mounting each sample in a closely similar manner to that used for the other samples.

C. Operation of High-Pressure Permeometer

The Georgia Tech high-pressure permeometer is capable of obtaining pressure differentials across the fabric sample equivalent to 1500 inches of water and dependent upon the resistance and strength of the test fabric. By means of the pressure-regulator valve in the air-supply line, it is possible to vary the test pressure differential.

Preliminary test runs were made to determine approximately the breaking pressure differential of the cloth in question. Then the test pressure range was divided into five or six increments below the rupture pressure. By means of variation of the pressure regulator, the cloth was subjected to each of the five or six test pressure increments. These data were used to obtain the character of the permeability-versus-pressure-differential curve. Then the last or maximum pressure was applied suddenly by opening

the cut-off valve wide and fast. Only the rupture pressure differential was measured from this portion of the oscillograph record. As stated previously, nine random samples of each fabric to be evaluated were subjected to this test procedure.

D. Handling of Data

From the oscillograph record, the pressure differential across the sample, pressure upstream of the orifice meter, pressure differential across the orifice meter, temperature of air at the orifice meter and at the fabric sample, and the magnitude of the fabric deformation under load will be obtained. Figure 10 is an example of the test data obtained from the oscillograph record for each of the nine samples. These data are averaged for use in subsequent steps. The curves are cut-off at the average rupture pressure differential.

Figure 11 demonstrates the Master Data and Result Sheet used in computing the permeability evaluations. Figure 12 is a sample showing typical computed results for a fabric being evaluated.

From the elongation or deformation measurements obtained during the tests, a fabric area increase factor is computed. These data are averaged and plotted for use in accounting for the fabric stretch under load. This factor is shown in item 23 of Figure 12. In the absence of observed deformation data, the area increase factor at rupture is obtained by adding one to the elongation at the breaking point determined on the biaxial tester and squaring the result. This value is the ordinate at the average fabric rupture pressure, and a straight-line variation between zero pressure and rupture pressure is assumed. Use of the approximate method for constructing the area increase factor in the absence of actual observed fabric deformation is better than ignoring elastic deformation of the fabric sample.

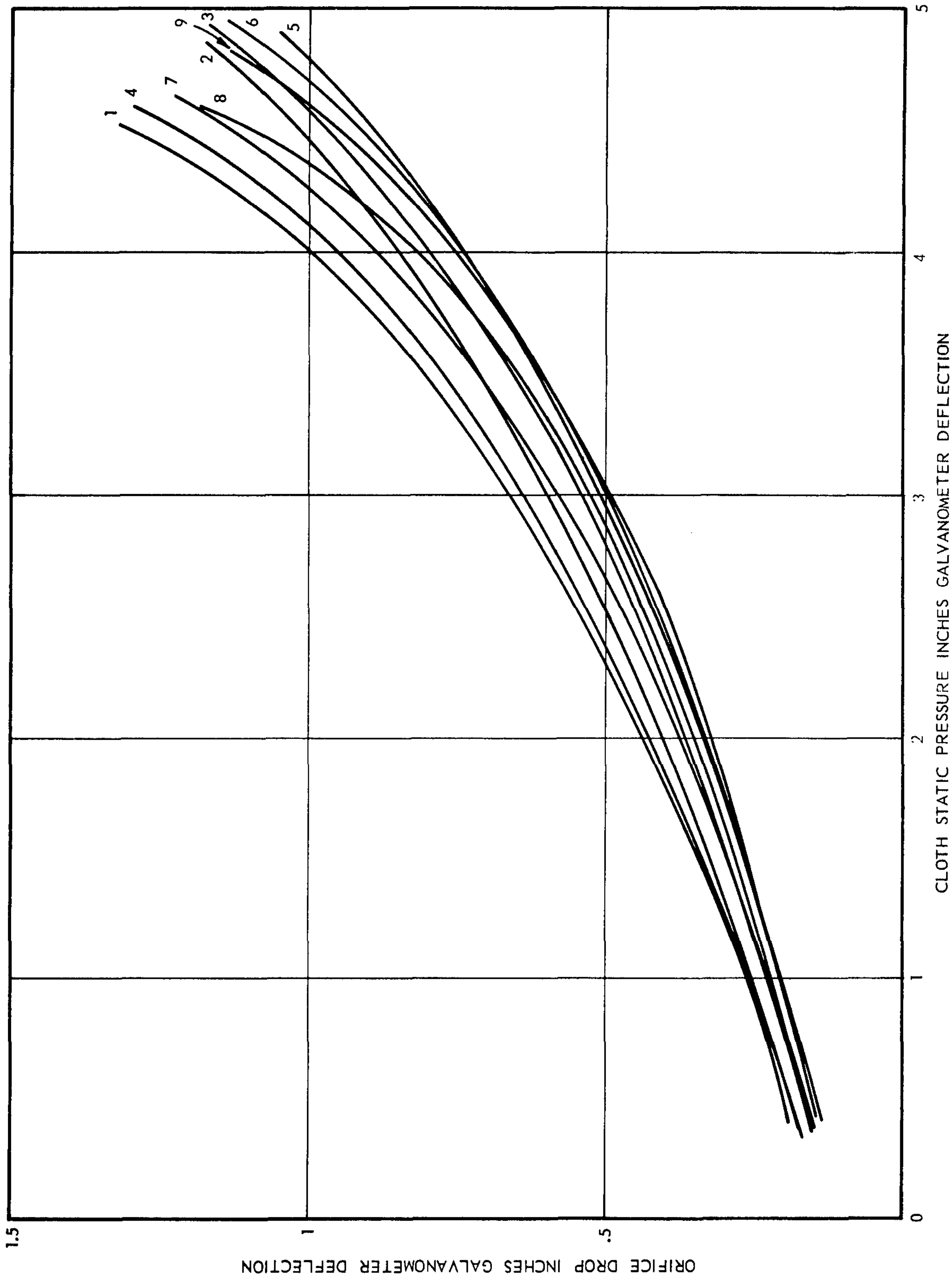


Figure 10. Curves for 9 Samples Reduced from Oscillograph Records of High-Pressure Permeability for Fabric GT-52 Dacron Twill 110 x 70.

MASTER DATA AND RESULT SHEET

Item No.	Sample	Dimension
1. Barometer (Data)	29.01	in. Hg.
2. Barometer (0.491 x item 1) 491x29.01 =	14.24	$lb_f in^{-2}$
3. Cloth Static Pressure (Data)	2.90	psig
4. Cloth Static Pressure (item 2 + item 3),		
14.24+2.90 =	17.14	psia
5. Cloth Static Pressure (item 3 x 27.7),		
27.7x2.90 =	80.3	in.W.G.
6. Temperature, T, (Data)	537.7	F. abs.
7. $2.71 \div T$, (From Curve)	0.00505	
8. Orifice Pressure Drop, ∇P, (Data)	4.30	psi
9. Air Density at cloth, ρ_c, (item 4 x item 7),		
17.14x0.00505 =	0.0866	$lb_m ft^{-3}$
10. $\nabla P \rho_c$, (item 8 x item 9), 4.30x0.0866 =	0.374	
11. $\sqrt{\nabla P \rho_c}$, (item 10)$^{1/2}$, $\sqrt{0.374}$ =	0.602	
12. Estimated Flow, W_e, β = 0.60; (2.03xitem 11)		
2.03x0.602 =	1.22	$lb_m sec^{-1}$
13. $\frac{C}{\mu}$ (From Curve) β = 0.60; C = 9335;		
(μ = Viscosity in cp)	507,900	$sec\ lb_m^{-1}$
14. Reynolds Number at throat, N_{Re},		
(item 13xitem 12) 507900x1.22 =	620,000	
15. Corrected Orifice Coefficient, K_c,		
(From Curve)	0.650	
16. Upstream Static Pressure, P_1, (Data)	19.72	psia

Figure 11. Master Data and Result Sheet.

MASTER DATA AND RESULT SHEET

Item No.	Sample	Dimension
17. KP_1, (1.4 x item 16), 1.4 x 19.72 =	27.61	
18. $\frac{\nabla P}{KP_1}$, (item 8 ÷ item 17), 4.30 ÷ 27.61 =	0.156	
19. Expansion Factor, Y_1, β = 0.60 (From Curve)	0.929	
20. $Y_1 \times W_e$, (item 19 x item 12), 0.929 x 1.22 =	1.13	
21. $\frac{K_c}{K}$, (item 15 ÷ 0.65) = (item 15 x 1.5385) $\frac{0.650}{0.650}$ =	1.000	
22. Corrected Flow, W_c, $\frac{Y_1 W_e K_c}{K}$, (item 20 x item 21) 1.13x1.0 =	1.13	$lb_n sec^{-1}$
23. $(1.00 + \text{Elongation})^2$, = Area Increase Factor	1.06	ft^2
24. (9.00 ÷ item 23), 9.00 ÷ 1.06 =	8.49	
25. Mass Velocity at Cloth, G, (item 24 x item 22), 8.49x1.13 =	9.59	$lb_m sec^{-1} ft^{-2}$
26. $\sqrt{\rho_c}$, (item 9)$^{1/2}$, $\sqrt{0.0866}$ =	0.293	
27. 219 x G (219 x item 25), 9.59 x 219 =	2100	
28. Permeability, $60G\sqrt{\rho_s \times \rho_c}$, (item 27 ÷ item 26), 2100÷.293 =	7167	
29. $\frac{\nabla P}{\rho}$ = (item 3 ÷ item 9), 2.90 ÷ 0.0866 =	33.49	
30. $\sqrt{\frac{\nabla P}{\rho}}$, $\sqrt{33.49}$ =	5.77	
31. $\sqrt{\frac{\nabla P}{\rho}} \times 96.2$ = 96.2 x 5.77 =	555.1	ft. sec^{-1}
32. $\frac{G}{\rho}$ (item 25 ÷ item 9) = 9.59 ÷ 0.0866 =	110.7	ft. sec^{-1}
33. $\frac{V2}{V1}$ = Effective Porosity = 110.7 ÷ 555.1 =	0.199	

Figure 11. Master Data and Result Sheet. (Continued)

SAMPLE CALCULATION SHEET

Cloth Identification		Ref: Log Sheet
Style No. GT-27	Color Style White 125 x 40	Run No. Average
Fiber Content Nylon	Piece No.	Page No.
Weave Pattern Satin		Computed by M. A. V.

Item Number	Test Number							
1	29.01	29.01	29.01	29.01	29.01	29.01	29.01	29.01
2	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24
3	2.90	6.80	9.40	13.10	15.60	19.20	22.00	26.40
4	17.14	21.04	23.64	27.34	29.84	33.44	36.24	40.64
5	80.33	188.36	260.38	362.87	432.12	531.84	609.40	731.28
6	537.7	537.7	537.7	537.7	537.7	537.7	537.7	537.7
7	.00505	.00505	.00505	.00505	.00505	.00505	.00505	.00505
8	4.30	6.90	8.60	11.20	12.90	15.70	17.40	20.00
9	.0866	.106	.119	.138	.151	.169	.183	.205
10	.374	.731	1.02	1.55	1.95	2.65	3.18	4.10
11	.602	.855	1.01	1.24	1.396	1.63	1.78	2.02
12	1.22	1.74	2.05	2.52	2.83	3.31	3.61	4.10
13	507900	507900	507900	507900	507900	507900	507900	507900
14	620000	884000	1041000	1280000	1412000	1681000	1834000	2082000
15	.650	.650	.650	.650	.650	.650	.650	.650
16	19.72	25.18	28.80	34.06	37.58	42.86	46.68	52.64
17	27.61	35.25	40.32	47.68	52.61	60.00	65.35	73.70
18	.156	.195	.213	.235	.245	.262	.266	.271
19	.9288	.9212	.9032	.893	.8884	.8804	.8789	.8766
20	1.13	1.60	1.85	2.25	2.51	2.91	3.17	3.59
21	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	1.13	1.60	1.85	2.25	2.51	2.91	3.17	3.59
23	1.060	1.140	1.196	1.276	1.327	1.402	1.460	1.55
24	8.49	7.89	7.53	7.05	6.78	6.42	6.16	5.81
25	9.59	12.62	13.92	15.86	17.02	18.68	19.53	20.9
26	.293	.326	.345	.371	.389	.411	.428	.453

Figure 12. Sample Calculation Sheet.

SAMPLE CALCULATION SHEET
(Continued)

Cloth Identification		Ref: Log Sheet
Style No. GT-27	Color Style White 125 x 40	Run No. Average
Fiber Content Nylon	Piece No.	Page No.
Weave Pattern Satin		Computed by M. A. V.

Item Number	Test Number							
27	2100	2764	3048	3473	3727	4091	4277	4577
28	7167	8479	8835	9361	9581	9954	9993	10104
29	33.49	64.15	78.99	94.93	103.3	113.6	120.2	129
30	5.77	8.01	8.88	9.74	10.14	10.67	10.95	11.4
31	555.1	770.6	854.3	937.0	975.5	1026.5	1053.4	1098
32	110.7	119.1	117.1	114.9	112.7	110.5	106.7	102
33	.199	.155	.137	.123	.116	.108	.101	.0929

Figure 12. Sample Calculation Sheet. (Continued)

After the volume flow per unit area at standard conditions versus pressure differential is obtained, the data are further operated to obtain the effective porosity coefficients $(\frac{V}{v})$. These coefficients represent the ratio of velocity approaching the parachute cloth divided by the velocity of flow through the fabric interstice.

E. Discussion of Obtaining Special Effects

Warm test temperatures of $+168^{\circ}F$ are obtained by shutting off the after-cooler and conducting tests immediately, before the air can cool off in the reservoir. Cold test temperatures as low as $-5^{\circ}F$ are obtained by introducing liquid nitrogen in the air stream.

Some variation of humidity will be obtained by shutting off the silica-gel adsorption dryer. However, in previous reports it has been shown that absolute humidity rather than relative humidity and lubrication effects of the moisture in the air on yarns is the reason for variation of air permeability with changes in humidity as is shown in the case of nylon, Orlon, and Dacron parachute-type cloths.

V. MECHANICS OF FLOW THROUGH FABRICS

It is not claimed that the research reported here has developed an analytical treatment of the flow of air through fabric. However, as a result of the experiments much useful knowledge concerning the flow of air through fabrics has resulted and this knowledge is here applied to reduce the number of pressure increments required in evaluating the air permeability of a fabric. Also the information presented here can be used in predicting the air permeability of a new fabric.

Cloth thickness, yarn denier, and fabric breaking strengths are determined in the course of conventional fabric analysis. The elongation of the fabric at time of tension failure is also a part of such analysis. Air-permeability data in the form of volume and mass flow per second versus pressure drop across the fabric sample are obtained by use of either the Air Force low-pressure air permeometer or by the Georgia Tech high-pressure permeometer. Extension or stretch of the cloth under air load is measured on the Georgia Tech high-pressure permeometer during test.

The area increase factor (I) is obtained by actually measuring the maximum ordinate of the stretched cloth downstream from the no air-flow position of the cloth and, by applying trigonometry and knowing the chord of the arc, computing the arc perimeter length. The square of the ratio of arc perimeter length divided by chord length is the area-increase factor. In the absence of measured fabric stretch under air loading, the tensile rupture elongation obtained by biaxial tests in warp and filling direction can be used. Here a number one plus the warp elongation in hundredths times one plus the filling elongation in hundredths is used as the area increase factor (I) at tensile rupture. Then a graph of (I) versus pressure differential is plotted, and this value is used in computing the permeability.

When the ratio of air pressure after the cloth to that upstream of the cloth is 0.53, the critical pressure ratio is attained. When the pressure ratio is less than critical, it may be presumed that the velocity of air through the interstice is sonic velocity. There is no apparent reason to believe that the flow through the interstices should be different than the flow through any converging orifice opening to the atmosphere. It is not the writer's opinion that due to the shape of the yarn cross section a

converging-diverging nozzle phenomenon occurs, or in other words it is not to be expected that supersonic flow will be encountered in the divergent regions just downstream of the minimum interstice projected area. Permeability curves presented in this report will have the critical pressure line indicated by r_c.

VI. DISCUSSION OF TEST RESULTS

The effect on air permeability resulting from variations of filling thread count is demonstrated in Figures 13 through 17. It is apparent that the air permeability is less if the filling thread count is greater. Figures 16 and 17 give the air permeability versus pressure differential for fabrics having 40 denier warp yarn and 70 denier filling yarn. Comparing the air-permeability evaluation for the 40/70 denier fabrics with the foregoing 70/70 denier fabrics, it is apparent that the amount of yarn material blocking the air flow affects the air permeability of the fabric. In short, an increase in the blocking material will result in lower air permeability.

The effect of variation of weave pattern on air permeability is shown in Figures 18 through 22. The fabrics studied included 40/70 denier nylon, 70/70 denier nylon, Orlon, and Dacron. Unfortunately, no distinct trend was revealed that would establish any one weave pattern as having a significant effect on air permeability of the fabric. It can be only concluded that other factors such as magnitude of blocking material, yarn twist, and calendering result in greater variations of fabric air permeability.

Variation of yarn twist and its effect on air permeability is studied in Figures 23 through 26. From these curves it is apparent that variation of twist has considerable effect on fabric air permeability. Infact, the low-filling-yarn twist is accompanied by low air permeability for the fabric. This is another evidence of the importance of the magnitude of material blocking on air permeability since the highly twisted yarns have a minimum diameter.

Figures 27 through 40 show the effective porosity coefficient versus pressure differential across the cloth sample. Like the air permeability results, biaxial-tension-test elongation data were used to correct the fabric sample area to indicate the effect of stretch under air loading. It is observed that in the case of the loosely woven fabrics the yarn elongation is great and the individual void or interstice opening enlarges with increasing air load. This results in letting more air through the interstice, but the ratio of interstice air velocity to approaching air velocity decreases as the air-pressure differential increases. However, in the case of the more tightly woven fabrics the curve of effective porosity coefficients is found to be almost horizontal at higher air-pressure differentials. This is indicative of less yarn elongation and less increase in interstice area as a result of fabric stretch.

A conventional ripstop nylon parachute fabric furnished by the Air Force has been studied at three temperatures. The 126 x 117 ripstop fabric shows greater permeability at 123°F than at 72°F. Similarly, the fabric is more permeable at 72°F than at -5°F. These results are presented in Figure 41 and are to be expected since the yarn elongation is greater at elevated temperature.

The Biaxial-Tension Measuring Sample Holder was tried out on the Georgia Tech High-Pressure Air Permeometer. The tension-load-versus-air-pressure results are presented in Figures 42 and 43. It is evident that the tension loads measured are affected by internal friction of the sample holder. It is not considered practical to further attempt friction elimination as this will result in air leakage at the fabric sample edges and will also invalidate air-flow quantity measurements. This sample holder is not considered satisfactory or practical.

Figure 44 shows the effective porosity variations with changing air-pressure differential as affected by a change in ambient air temperature.

VII. CONCLUSIONS

1. It is evident that the number and the size of warp and filling threads have the greatest effect on air permeability of the various parachute type synthetic fabrics studied.

2. The weave pattern does not seem to have a significant effect on the air permeability of a woven cloth.

3. Yarn twist is found to have a considerable effect on the air permeability of fabrics.

4. High temperatures result in high-air-permeability and low-temperatures result in considerably lower air permeability.

5. The lack of comparable nylon, Orlon, and Dacron yarns makes it impossible to draw conclusions regarding the merits of one material over another.

6. The Biaxial-Tension Measuring Sample Holder was not satisfactory.

7. A simple plain weave is as good a weave pattern as any.

8. Air-permeability evaluations conducted at ambient or machine operating temperatures (about 80°F) and reduced to standard conditions are satisfactory for practical fabric design purposes.

BIBLIOGRAPHY

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2. Binder, Fluid Mechanics. Prentice Hall, New York, 1949.

APPENDIX I

TABLES

TABLE I

PHYSICAL AND TEXTILE PROPERTIES OF
GEORGIA TECH FABRICS

Fabric Number	1	2	6	8	9	12	15	18	22
Fiber Content	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon
Width (Inches)	32-1/2	33	33	32	32	34	34	33-1/4	32-1/2
Construction:	Plain	Satin	Satin	Plain	Plain	Twill	Twill	Plain	Plain
Finished	77x44	75.5x91	77x43.5	78x88	78.5x73	74x42	74x73	137x41	142.25x82.25
Warp Yarns:									
Denier	70	70	70	70	70	70	70	70	40
Filaments	34	34	34	34	34	34	34	13	13
Filling Yarns:									
Denier	70	70	70	70	70	70	70	70	70
Filaments	34	34	34	34	34	34	34	34	34
Weight:									
Oz./Sq.Yard	1.23	1.82	1.17	1.67	1.58	1.12	1.46	1.11	1.68
Oz./Lin.Yard	1.11	1.67	1.07	1.48	1.40	1.06	1.38	1.02	1.52
Twist:									
Filling	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Warp	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.8	9.8
Elongation(%):									
Filling	30.0	36.7	30.6	35.3	36.6	30.0	32.6	32.0	37.3
Warp	34.5	38.3	33.3	35.9	34.0	36.0	34.3	31.6	30.3
Tensile:									
Filling	52	97	37	81	80	53	99	43	100
Warp	83	81	65	81	80	79	88	72	73

(Continued)

TABLE I (Continued)

PHYSICAL AND TEXTILE PROPERTIES OF
GEORGIA TECH FABRICS

Fabric Number	27	28	30	40	44	52	56
Fiber Content	Nylon	Nylon	Nylon	Orlon	Orlon	Dacron	Dacron
Width (Inches)	33	32-1/2	32-1/2	34-3/4	35	32	32
Construction: Finished	Satin 137.5x42.5	Twill 139.5x42	Twill 141x5x63.75	Twill 103x70	Satin 102x70	Twill 123x77	Satin 123x78
Warp Yarns:							
Denier	40	40	40	75	75	70	70
Filaments	13	13	13	30	30	34	34
Filling Yarns:							
Denier	70	70	70	75	75	70	70
Filaments	34	34	34	30	30	34	34
Weight:							
Oz./Sq.Yard	1.21	1.23	1.45	1.75	1.75	2.10	2.13
Oz./Lin.Yard	1.11	1.11	1.31	1.69	1.70	1.87	1.90
Twist:							
Filling	0.86	0.86	0.86	0.80	0.80	1.0	1.0
Warp	9.8	9.8	9.8	7.6	7.6	15.9	15.9
Elongation (%):							
Filling	30.0	33.3	36.6	16.3	15.0	31.7	35.3
Warp	33.3	34.0	33.3	12.3	12.0	34.0	33.0
Tensile:							
Filling	48.0	52.0	81.0	41.5	43.8	71.8	83.4
Warp	80.0	83.0	86.0	52.6	52.1	107	108

TABLE II

PHYSICAL AND TEXTILE PROPERTIES OF CHENEY BROTHERS FABRICS

Fabric Number	7C1/2	7C35	7N1/2	7N7	7N35
Fiber Content	Nylon	Nylon	Nylon	Nylon	Nylon
Construction:	Plain	Plain	Plain	Plain	Plain
Finished	130x79	130x78	131x77	128x78	126x76
Warp Yarns:					
Denier	40	40	40	40	40
Filaments	13	13	13	13	13
Filling Yarns:					
Denier	70	70	70	70	70
Filaments	34	34	34	34	34
Twist:					
Filling	1.0	39.6	1.2	7.8	39.3
Warp	7.7	7.8	7.9	8.0	7.7
Elongation (%):					
Filling	31.1	47.3	39.0	40.7	43.0
Warp	32.2	33.4	32.0	31.3	30.1

(Continued)

TABLE II

PHYSICAL AND TEXTILE PROPERTIES OF
CHENEY BROTHERS FABRICS

Fabric Number	10N1/2	10N7	10N35	7N1/2R	7N7R	7N30R
Fiber Content	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon
Construction:	Plain	Plain	Plain	Ripstop	Ripstop	Ripstop
Finished	130x77	130x77	124x78	126x120	124x119	121x120
Warp Yarns:						
Denier	40	40	40	40	40	40
Filaments	13	13	13	13	13	13
Filling Yarns:						
Denier	70	70	70	70	70	70
Filaments	34	34	34	34	34	34
Twist:						
Filling	1.0	7.4	38.6			
Regular				1.2	8.6	33.0
Ripstop				1.2	8.6	32.7
Warp	10.9	10.6	10.3			
Regular				7.5	7.6	8.2
Ripstop				7.9	7.7	7.7
Elongation (%):						
Filling	35.8	41.1	44.3			
Regular				33.3	38.4	36.3
Ripstop				34.3	38.2	37.5
Warp	32.4	33.7	31.4			
Regular				25.5	29.5	32.0
Ripstop				27.2	27.6	35.4

TABLE III

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth ($lbm\ ft.^{-3}$)	Mass Velocity of Air Upstream of Cloth ($lbm\ sec.^{-1} ft.^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability ($cfm\ ft.^{-2}$)
GEORGIA TECH WOVEN FABRICS:				
Fabric Number 1 (GT-1)				
69	0.0848	11.3	25.5	8,510
130	0.0958	14.2	22.0	10,000
188	0.106	16.0	19.5	10,800
249	0.117	17.7	17.9	11,300
310	0.128	18.9	16.4	11,600
368	0.139	20.2	15.4	11,900
Fabric Number 2 (GT-2)				
55	0.0837	4.74	12.1	3,590
97	0.0914	5.79	10.6	4,200
163	0.104	6.76	8.97	4,600
231	0.116	7.59	8.01	4,870
360	0.140	9.47	7.29	5,550
485	0.163	10.9	6.75	5,910
596	0.183	12.4	6.53	6,350
668	0.197	13.1	6.23	6,480
731	0.208	13.9	6.15	6,680
795	0.220	14.5	6.01	6,770
Fabric Number 6 (GT-6)				
15	0.0748	6.56	33.9	5,250
45	0.0824	9.65	27.4	7,360
75	0.0857	11.4	24.8	8,520
105	0.0912	12.8	22.6	9,280
135	0.0966	13.9	21.1	9,790
165	0.102	14.8	19.8	10,100
195	0.108	15.5	18.5	10,400
224	0.113	16.1	17.6	10,500
254	0.118	16.7	16.6	10,600

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth	Air Density Upstream of Cloth	Mass Velocity of Air Upstream of Cloth	Effective Porosity of Cloth	Permeability
(Inches of Water)	($lbm\ ft.^{-3}$)	($lbm\ sec.^{-1} ft.^{-2}$)	(per cent)	($cfm\ ft.^{-2}$)
Fabric Number 8 (GT-8)				
127	0.0974	4.11	6.38	2,890
260	0.122	5.53	5.37	3,470
391	0.146	6.77	4.90	3,880
521	0.170	7.81	4.54	4,140
651	0.194	8.70	4.23	4,330
778	0.218	9.68	4.05	4,540
831	0.229	10.1	3.99	4,620
Fabric Number 9 (GT-9)				
138	0.0917	6.58	10.1	4,760
208	0.104	7.68	9.05	5,220
277	0.115	8.68	8.39	5,590
346	0.127	9.44	7.79	5,790
415	0.139	10.2	7.33	5,990
554	0.163	11.5	6.61	6,240
623	0.175	12.1	6.31	6,340
693	0.187	12.6	6.05	6,390
761	0.199	13.2	5.86	6,480
831	0.210	13.7	5.64	6,540
900	0.222	14.4	5.57	6,680
Fabric Number 12 (GT-12)				
71	0.0872	11.5	25.3	8,540
101	0.0927	13.2	23.5	9,510
131	0.0987	14.8	22.6	10,300
190	0.109	17.2	20.6	11,400
220	0.115	18.3	19.9	11,800
279	0.126	20.1	18.6	12,400
309	0.131	20.9	18.0	12,600
339	0.137	21.7	17.4	12,800
398	0.148	23.1	16.4	13,200
428	0.153	23.7	15.9	13,300
457	0.159	24.5	15.7	13,500

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
Fabric Number 15 (GT-15)				
30	0.0776	3.55	11.1	2,450
97	0.0897	6.25	9.85	3,880
241	0.116	8.95	9.27	5,750
374	0.140	11.6	8.77	6,800
496	0.162	14.0	8.55	7,610
615	0.183	16.2	8.36	8,290
743	0.206	18.1	8.01	8,730
823	0.221	19.5	7.91	9,090
875	0.230	20.3	7.83	9,260
1000	0.254	22.0	7.54	9,560
Fabric Number 18 (GT-18)				
72	0.0862	8.06	17.7	6,030
102	0.0917	9.60	17.3	6,940
132	0.0972	10.8	16.5	7,580
161	0.103	11.9	16.2	8,120
191	0.108	12.9	15.5	8,590
221	0.114	13.9	15.2	9,010
251	0.119	14.7	14.8	9,330
283	0.125	15.4	14.3	9,530
310	0.130	16.0	13.8	9,710
341	0.136	16.6	13.3	9,850
371	0.141	17.2	13.0	10,000
Fabric Number 22 (GT-22)				
100	0.0864	4.21	7.83	3,140
200	0.104	5.58	6.70	3,800
300	0.121	7.21	6.55	4,540
400	0.138	8.79	6.49	5,190
500	0.155	10.2	6.33	5,670
600	0.173	11.5	6.17	6,060
700	0.190	12.8	6.09	6,430
800	0.207	13.8	5.84	6,640

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
Fabric Number 27 (GT-27)				
79	0.0862	8.23	17.2	6,130
154	0.0993	11.4	16.0	7,930
203	0.108	13.0	15.1	8,650
277	0.123	15.1	14.2	9,420
327	0.131	16.2	13.6	9,800
402	0.145	17.8	12.8	10,200
452	0.154	18.8	12.3	10,500
526	0.167	20.1	11.7	10,800
Fabric Number 28 (GT-28)				
55	0.0958	6.96	16.5	4,920
111	0.108	9.65	15.3	6,460
166	0.119	11.8	14.5	7,490
222	0.131	13.6	13.8	8,230
277	0.143	15.2	13.2	8,810
332	0.155	16.6	12.6	9.230
388	0.166	18.0	12.2	9,690
443	0.178	19.3	11.8	10,020
Fabric Number 30 (GT-30)				
41	0.0779	1.56	4.74	1,230
97	0.0877	3.46	6.50	2,560
180	0.102	5.12	6.54	3,490
233	0.112	5.97	6.40	3,900
313	0.126	7.14	6.22	4,410
366	0.135	8.00	6.24	4,770
438	0.148	8.97	6.09	5,100
488	0.157	9.70	6.07	5,360
562	0.170	10.7	5.99	5,690
612	0.179	11.3	5.91	5,850

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
Fabric Number 40 (GT-40)				
91	0.0884	2.59	5.00	1910
159	0.101	3.22	4.41	2220
227	0.113	3.89	4.21	2540
291	0.125	4.53	4.12	2800
358	0.137	5.26	4.12	3110
423	0.148	5.96	4.14	3390
484	0.160	6.62	4.11	3636
548	0.171	7.36	4.15	3890
609	0.182	7.95	4.13	4080
Fabric Number 44 (GT-44)				
66	0.0820	3.51	8.23	2690
130	0.0932	3.91	6.15	2810
175	0.101	4.28	5.58	2950
244	0.113	4.92	5.12	3210
313	0.125	5.74	5.02	3550
352	0.132	6.19	4.97	3740
388	0.139	6.49	4.85	3810
435	0.147	7.09	4.86	4060
482	0.155	7.85	4.96	4360
Fabric Number 52 (GT-52)				
139	0.0986	6.36	9.42	4440
263	0.121	7.42	7.19	4700
391	0.145	8.58	6.24	4930
515	0.167	9.82	5.82	5260
643	0.191	11.0	5.44	5510
767	0.214	12.1	5.15	5720
892	0.236	13.4	5.04	6040
1020	0.259	14.7	4.96	6320
1150	0.283	16.2	4.91	6670

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
Fabric Number 56 (GT-56)				
139	0.100	4.66	6.85	3,240
266	0.123	6.54	6.27	4,080
391	0.146	8.12	5.88	4,650
515	0.169	9.95	5.83	5,300
640	0.192	11.7	5.76	5,850
765	0.215	13.4	5.73	6,330
889	0.238	15.0	5.65	6,730
1020	0.262	16.6	5.59	7,100
CHENEY BROTHERS FABRICS:				
7C 1/2				
91	0.0890	5.44	10.4	4,000
176	0.105	6.35	8.11	4,300
260	0.120	7.13	6.99	4,510
344	0.135	7.93	6.36	4,720
428	0.151	8.61	5.87	4,860
512	0.166	9.24	5.49	4,970
596	0.181	9.92	5.22	5,100
680	0.197	10.5	4.97	5,190
764	0.212	11.2	4.80	5,310
848	0.227	11.9	4.70	5,480
881	0.234	12.0	4.58	5,440
7C 35				
96	0.0870	7.54	14.3	5,600
139	0.0947	9.79	14.7	6,960
183	0.102	11.8	15.0	8,100
226	0.110	13.4	14.7	8,840
270	0.118	14.7	14.3	9,360
328	0.128	16.4	13.8	10,000
386	0.138	17.9	13.4	10,570
444	0.149	19.4	13.0	11,000
488	0.156	20.3	12.7	11,260
531	0.164	21.4	12.5	11,550

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
7N 1/2				
117	0.0921	6.11	10.2	4,410
229	0.112	7.89	8.51	5,160
341	0.132	9.39	7.65	5,650
397	0.143	10.2	7.38	5,890
509	0.163	11.2	6.76	6,110
565	0.173	11.8	6.52	6,210
621	0.183	12.4	6.35	6,340
677	0.193	13.0	6.21	6,470
789	0.213	14.4	6.09	6,860
845	0.223	15.3	6.09	7,080
901	0.233	16.3	6.15	7,390
7N 7				
64	0.0837	6.29	14.8	4,760
134	0.0964	8.76	13.4	6,180
204	0.109	10.6	12.3	7,010
274	0.122	12.1	11.5	7,610
344	0.135	13.5	10.8	8,030
413	0.147	14.8	10.4	8,430
483	0.160	16.1	9.98	8,810
553	0.173	17.2	9.64	9,150
623	0.186	18.5	9.40	9,380
693	0.199	19.5	9.09	9,580
723	0.204	19.9	8.97	9,650
7N 35				
35	0.0764	7.21	24.3	5,710
93	0.0866	11.1	21.4	8,250
151	0.0970	13.5	19.4	9,520
209	0.107	15.4	17.7	10,270
238	0.112	16.1	17.0	10,520
296	0.123	17.4	15.8	10,870
354	0.133	18.5	14.7	11,110
412	0.143	19.6	13.9	11,300
470	0.154	20.6	13.2	11,490
528	0.164	21.4	12.6	11,550

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
10N 1/2				
120	0.0926	6.22	10.2	4,480
204	0.108	7.68	8.94	5,110
288	0.123	8.88	8.16	5,540
372	0.138	9.94	7.59	5,870
456	0.153	10.9	7.12	6,100
540	0.168	11.8	6.75	6,300
624	0.183	12.7	6.49	6,500
708	0.198	13.6	6.25	6,700
792	0.213	14.7	6.16	6,970
10N 7				
96	0.0874	7.36	13.9	5,460
168	0.100	10.0	13.3	6,910
241	0.113	12.1	12.7	7,880
314	0.126	13.8	12.0	8,510
386	0.139	15.4	11.5	9,020
459	0.152	16.8	11.0	9,430
531	0.165	18.0	10.5	9,700
604	0.179	19.3	10.1	10,020
676	0.191	20.5	9.83	10,280
749	0.204	21.7	9.65	10,530
790	0.211	22.4	9.54	10,700
10N 35				
22	0.0749	6.82	28.9	5,460
64	0.0825	10.8	25.7	8,260
120	0.0925	13.6	22.4	9,820
176	0.103	15.6	20.1	10,680
232	0.113	17.1	18.4	11,180
287	0.123	18.4	16.9	11,480
343	0.133	19.4	15.7	11,660
399	0.143	20.3	14.7	11,750
455	0.153	21.0	13.8	11,750

(Continued)

TABLE III (Continued)

HIGH-PRESSURE PERMEABILITY TEST RESULTS

Static Pressure Upstream of Cloth (Inches of Water)	Air Density Upstream of Cloth (lbm ft.$^{-3}$)	Mass Velocity of Air Upstream of Cloth (lbm sec.$^{-1}$ft.$^{-2}$)	Effective Porosity of Cloth (per cent)	Permeability (cfm ft.$^{-2}$)
7N 1/2 R				
93	0.0884	6.22	11.9	4,590
163	0.101	8.24	11.1	5,680
234	0.114	9.68	10.3	6,270
304	0.127	11.1	9.75	6,810
374	0.139	12.3	9.36	7,240
445	0.152	13.6	9.03	7,640
515	0.165	14.8	8.74	7,960
585	0.180	16.0	8.54	8,260
628	0.185	16.6	8.39	8,440
7N 7 R				
50	0.0801	6.91	18.8	5,350
98	0.0885	9.41	17.4	6,940
149	0.0978	11.7	16.8	8,190
206	0.108	13.5	15.7	8,990
262	0.118	15.1	14.9	9,610
318	0.128	16.3	13.9	9,970
374	0.138	17.5	13.4	10,300
430	0.148	18.7	12.8	10,600
473	0.156	19.5	12.5	10,800
515	0.164	20.3	12.1	11,000
7N 30 R				
22	0.0761	7.74	32.6	6,140
57	0.0830	10.9	27.6	8,320
91	0.0889	13.0	25.0	9,570
127	0.0955	14.2	22.3	10,070
163	0.102	15.0	20.2	10,300
197	0.108	15.7	18.6	10,440
233	0.115	16.2	17.1	10,470
267	0.122	16.7	16.0	10,470
302	0.127	16.8	14.8	10,330

TABLE IV

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
GEORGIA TECH FABRICS:		
Fabric Number 1(GT-1)		
69	0.049	1.10
130	0.086	1.18
188	0.123	1.26
249	0.162	1.35
310	0.200	1.44
368	0.233	1.52
Fabric Number 2(GT-2)		
55	0.020	1.04
97	0.034	1.07
163	0.054	1.11
231	0.077	1.16
360	0.118	1.25
485	0.153	1.33
596	0.187	1.41
668	0.208	1.46
731	0.225	1.50
795	0.241	1.54
Fabric Number 6(GT-6)		
15	0.015	1.03
45	0.049	1.10
75	0.077	1.16
105	0.105	1.23
135	0.136	1.29
165	0.166	1.36
195	0.192	1.42
224	0.221	1.49
254	0.245	1.55

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 8(GT-6)		
127	0.058	1.12
260	0.114	1.24
391	0.166	1.36
521	0.217	1.48
651	0.261	1.59
778	0.308	1.71
831	0.327	1.76
Fabric Number 9(GT-9)		
138	0.058	1.12
208	0.086	1.18
277	0.118	1.25
346	0.145	1.31
415	0.171	1.37
554	0.221	1.49
623	0.245	1.55
693	0.273	1.62
761	0.296	1.68
831	0.319	1.74
900	0.342	1.80
Fabric Number 12(GT-12)		
71	0.034	1.07
101	0.044	1.09
131	0.058	1.12
190	0.086	1.18
220	0.095	1.20
279	0.123	1.26
309	0.136	1.29
339	0.149	1.32
398	0.170	1.37
428	0.183	1.40
457	0.192	1.42

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 15(GT-15)		
30	0.010	1.02
97	0.030	1.06
241	0.072	1.15
374	0.109	1.23
496	0.140	1.30
615	0.175	1.38
743	0.204	1.45
823	0.225	1.50
875	0.237	1.53
1001	0.269	1.61
Fabric Number 18(GT-18)		
72	0.034	1.07
102	0.054	1.11
132	0.068	1.14
161	0.082	1.17
191	0.095	1.20
221	0.109	1.23
251	0.123	1.26
283	0.136	1.29
310	0.149	1.32
341	0.162	1.35
371	0.175	1.38
Fabric Number 22(GT-22)		
100	0.025	1.05
200	0.049	1.10
300	0.072	1.15
400	0.096	1.20
500	0.118	1.25
600	0.140	1.30
700	0.162	1.35
800	0.183	1.40

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 27(GT-27)		
79	0.039	1.08
154	0.072	1.15
203	0.095	1.20
277	0.131	1.28
327	0.153	1.33
402	0.183	1.40
452	0.200	1.44
526	0.237	1.53
Fabric Number 28(GT-28)		
55	0.025	1.05
111	0.049	1.10
166	0.072	1.15
222	0.096	1.20
277	0.118	1.25
332	0.140	1.30
388	0.162	1.35
443	0.183	1.40
Fabric Number 30(GT-30)		
42	0.020	1.04
97	0.049	1.10
180	0.086	1.18
233	0.109	1.23
313	0.145	1.31
366	0.162	1.36
438	0.200	1.44
488	0.221	1.49
562	0.249	1.56
612	0.269	1.61

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 40(GT-40)		
91	0.025	1.05
159	0.044	1.09
227	0.063	1.13
291	0.082	1.17
358	0.100	1.21
423	0.118	1.25
484	0.136	1.29
548	0.153	1.33
609	0.166	1.36
Fabric Number 44(GT-44)		
66	0.025	1.05
130	0.044	1.09
175	0.058	1.12
244	0.082	1.17
313	0.105	1.22
352	0.118	1.25
388	0.127	1.27
435	0.145	1.31
482	0.158	1.34
Fabric Number 52(GT-52)		
139	0.039	1.08
263	0.072	1.15
391	0.109	1.23
515	0.140	1.30
643	0.175	1.38
767	0.204	1.45
892	0.233	1.52
1019	0.265	1.60
1147	0.292	1.67

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 56(GT-56)		
139	0.049	1.10
266	0.091	1.19
391	0.131	1.28
515	0.171	1.37
640	0.204	1.45
765	0.241	1.54
889	0.277	1.63
1017	0.312	1.72
CHENEY BROTHERS FABRICS:		
Fabric Number 7C 1/2		
91	0.034	1.07
176	0.063	1.13
260	0.095	1.20
344	0.123	1.26
428	0.153	1.33
512	0.179	1.39
596	0.204	1.45
680	0.233	1.52
764	0.257	1.58
848	0.285	1.65
881	0.311	1.72
Fabric Number 7C 35		
96	0.044	1.09
139	0.063	1.13
183	0.082	1.17
226	0.100	1.21
270	0.118	1.25
328	0.145	1.31
386	0.166	1.36
444	0.196	1.43
488	0.208	1.46
531	0.225	1.50

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 7N 1/2		
117	0.039	1.08
229	0.077	1.16
341	0.109	1.23
397	0.127	1.27
509	0.162	1.35
565	0.179	1.39
621	0.196	1.43
677	0.208	1.46
789	0.237	1.54
845	0.257	1.58
901	0.273	1.62
Fabric Number 7N 7		
64	0.025	1.05
134	0.049	1.10
204	0.082	1.17
274	0.105	1.22
344	0.131	1.28
413	0.158	1.34
483	0.183	1.40
553	0.204	1.45
623	0.229	1.51
693	0.253	1.57
723	0.261	1.59
Fabric Number 7N 35		
35	0.020	1.04
93	0.054	1.11
151	0.082	1.17
209	0.114	1.24
238	0.127	1.27
296	0.158	1.34
354	0.187	1.41
412	0.212	1.47
470	0.241	1.54
528	0.265	1.60

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 10N 1/2		
120	0.049	1.10
204	0.082	1.17
288	0.114	1.24
372	0.140	1.30
456	0.170	1.37
540	0.200	1.44
624	0.229	1.51
708	0.257	1.58
792	0.285	1.65
Fabric Number 10N 7		
96	0.034	1.07
168	0.063	1.13
241	0.086	1.18
314	0.114	1.24
386	0.140	1.30
459	0.162	1.35
531	0.187	1.41
604	0.208	1.46
676	0.233	1.52
749	0.253	1.57
790	0.265	1.60
Fabric Number 10N 35		
22	0.015	1.03
64	0.044	1.09
120	0.082	1.17
176	0.114	1.24
232	0.149	1.32
287	0.183	1.40
343	0.217	1.48
399	0.245	1.55
455	0.277	1.63

(Continued)

TABLE IV (Continued)

AREA INCREASE FACTORS

Static Pressure Upstream of Cloth (Inches of Water)	Elongation (Inches/inch)	Area Increase Factor $(1 + \text{Elongation})^2$
Fabric Number 7N 1/2 Ripstop		
93	0.049	1.10
163	0.077	1.16
234	0.109	1.23
304	0.140	1.30
374	0.170	1.37
445	0.200	1.44
515	0.229	1.51
585	0.257	1.58
628	0.273	1.62
Fabric Number 7N 7 Ripstop		
50	0.025	1.05
98	0.049	1.10
149	0.072	1.15
206	0.100	1.21
262	0.127	1.27
318	0.153	1.33
374	0.179	1.39
430	0.200	1.44
473	0.221	1.49
515	0.237	1.53
Fabric Number 7N 30 Ripstop		
22	0.025	1.05
57	0.063	1.13
91	0.095	1.20
127	0.131	1.28
163	0.166	1.36
197	0.196	1.43
233	0.229	1.51
267	0.261	1.59
302	0.292	1.67

APPENDIX II

FIGURES 13 through 44

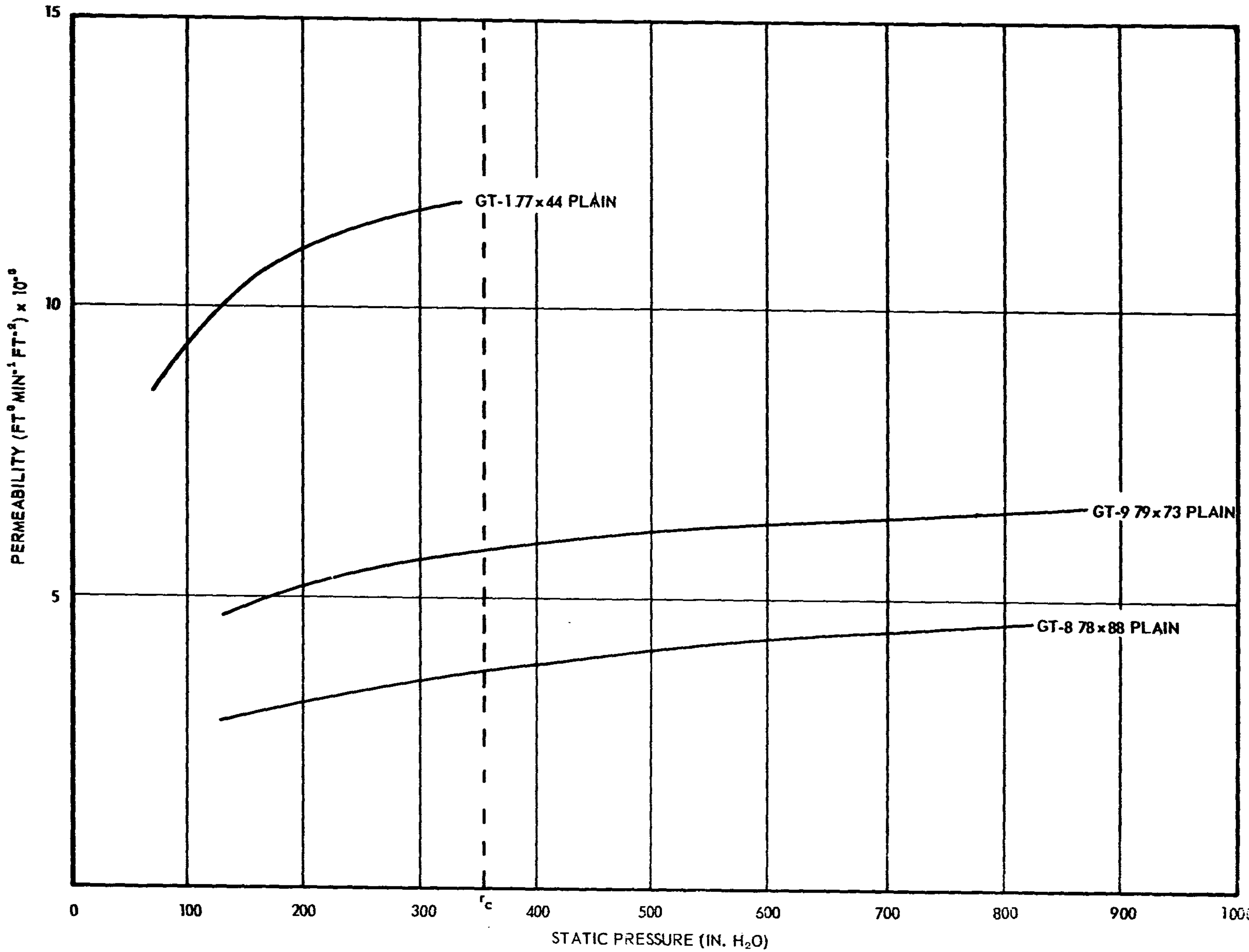

Figure 13. Effect of Pick Variation on Air Permeability of 70/70 Denier Nylon Cloth.

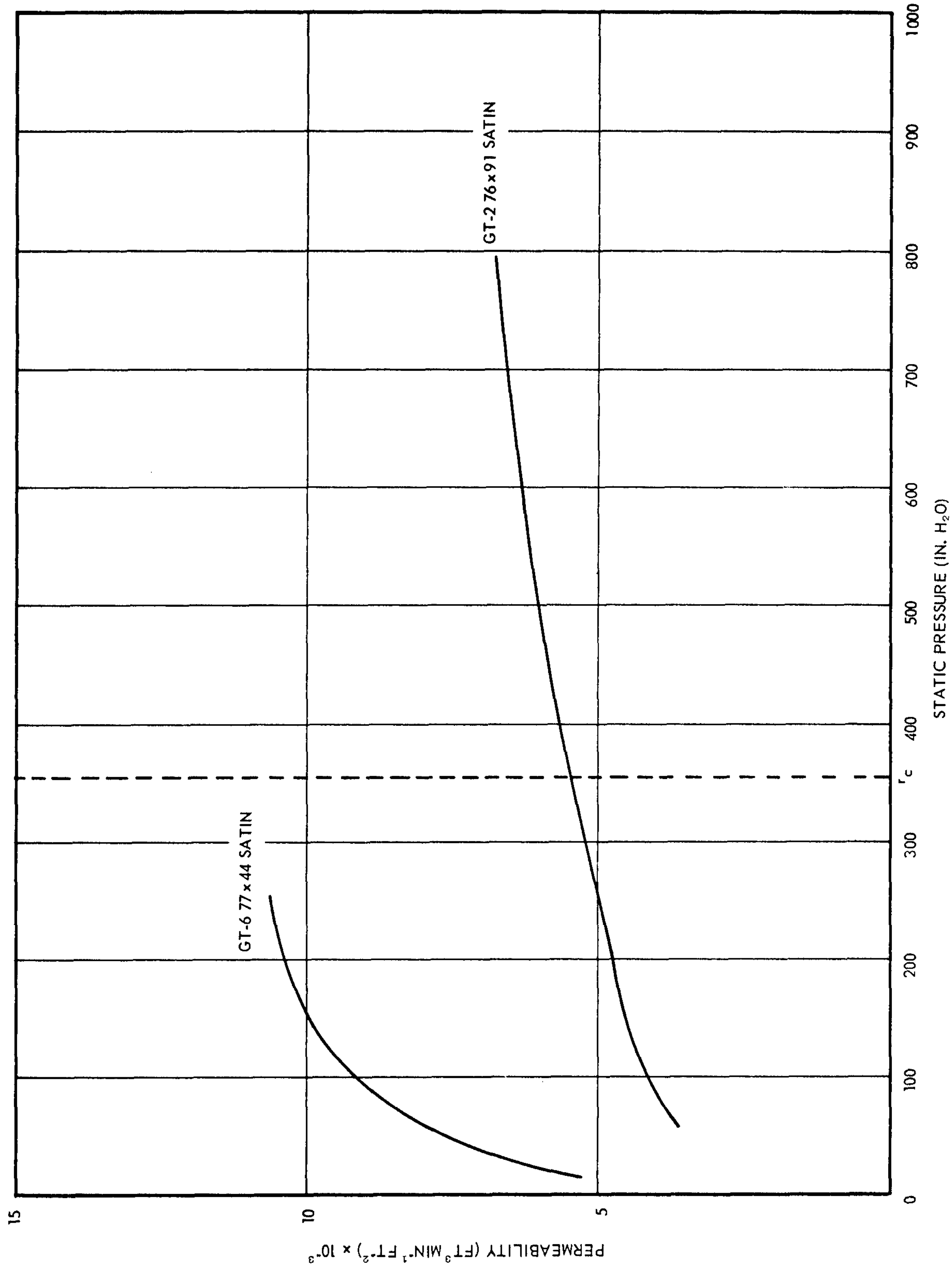

Figure 14. Effect of Pick Variation on Air Permeability of 70/70 Denier Nylon Cloth.

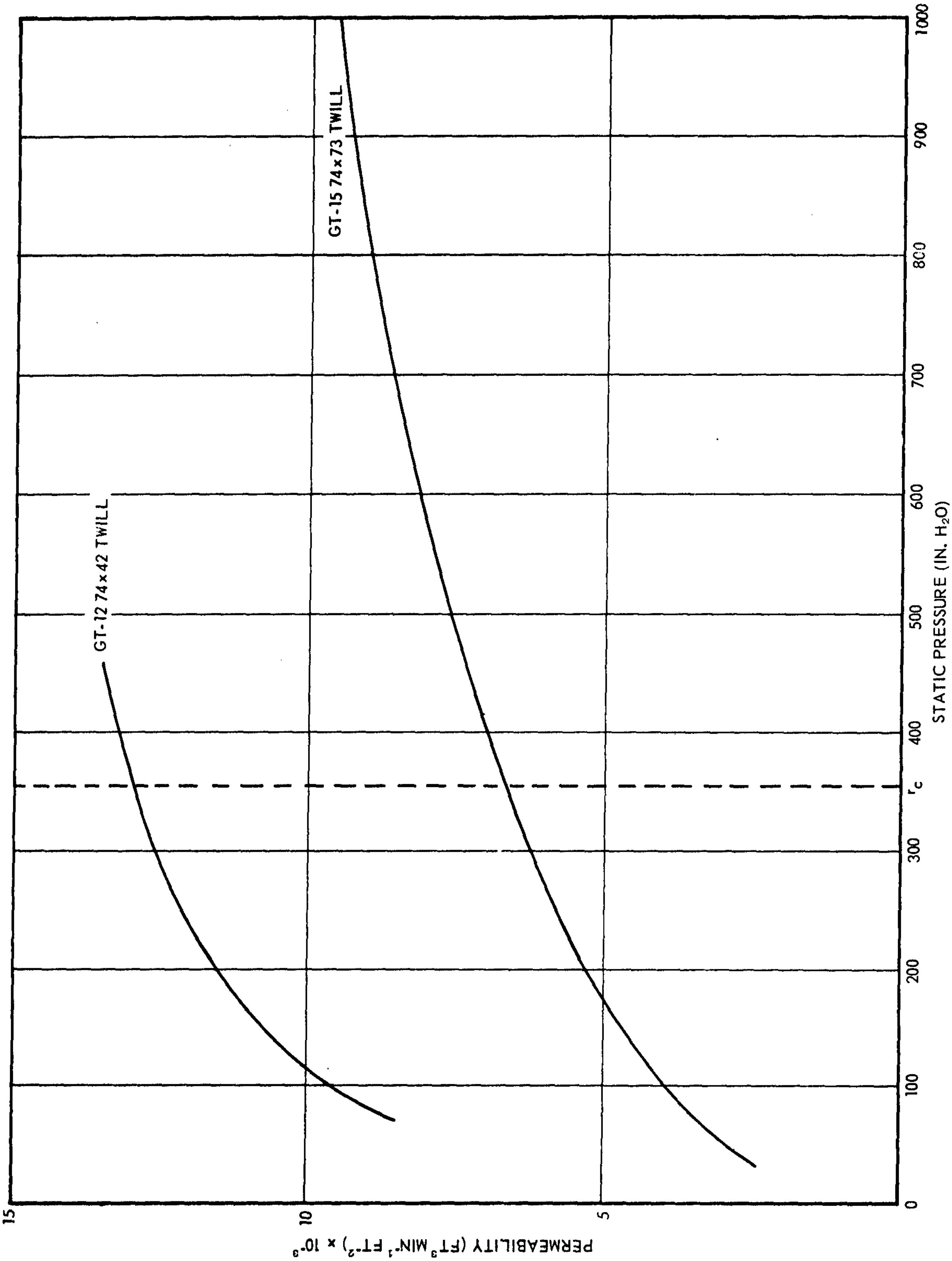

Figure 15. Effect of Pick Variation on Air Permeability of 70/70 Denier Nylon Cloth.

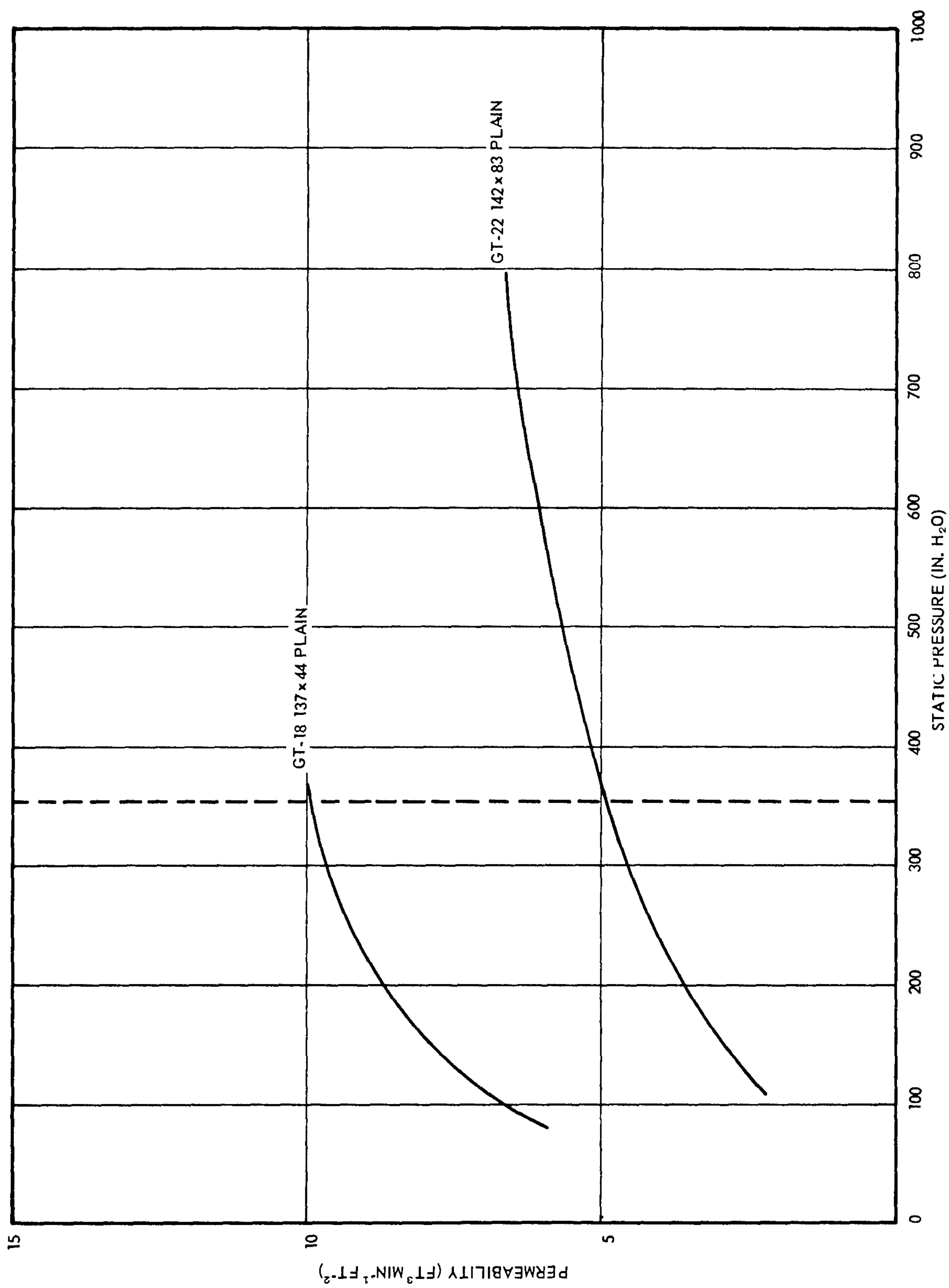

Figure 16. Effect of Pick Variation on Air Permeability of 40/70 Denier Nylon Cloth.

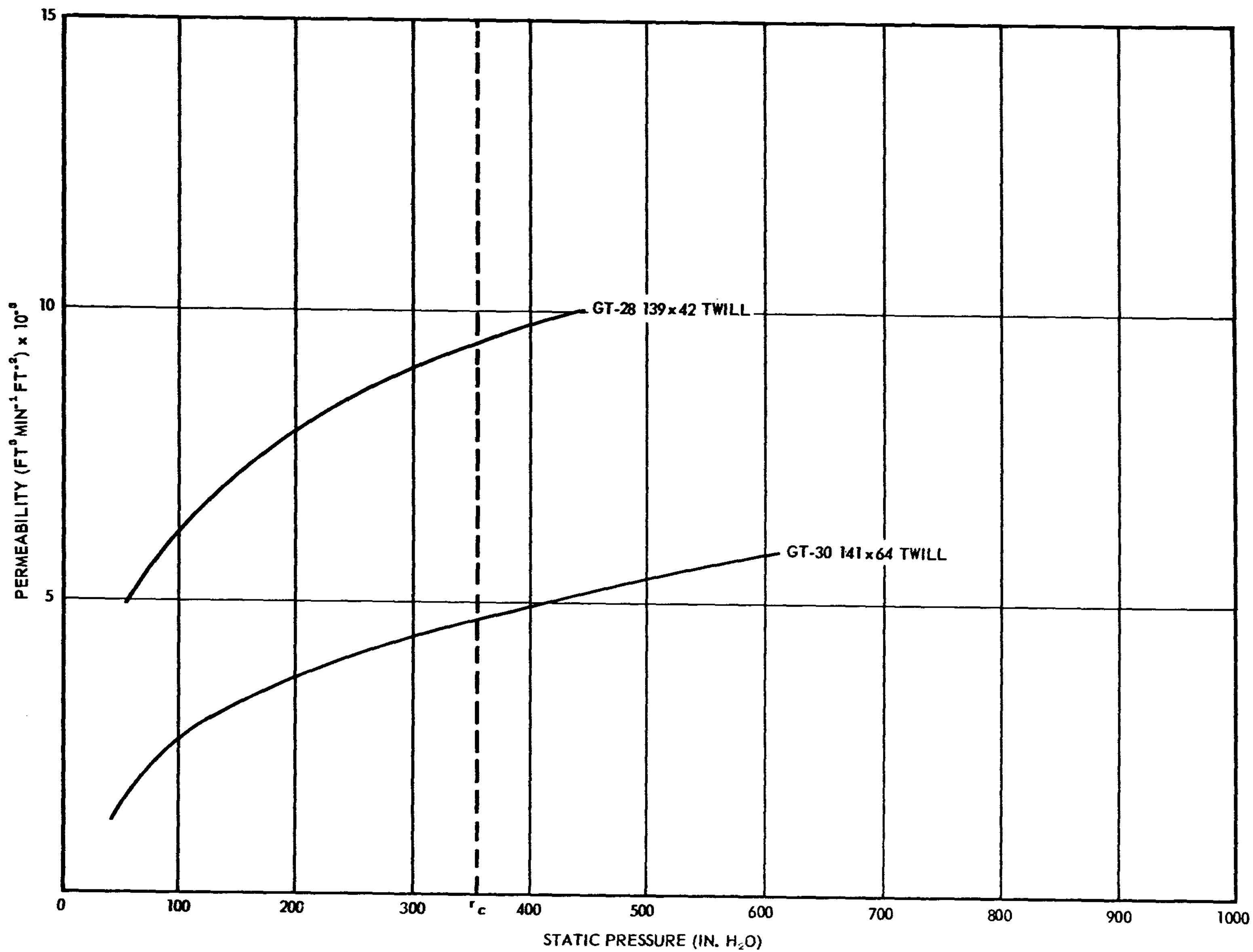

Figure 17. Effect of Pick Variation on Air Permeability of 40/70 Denier Nylon Cloth.

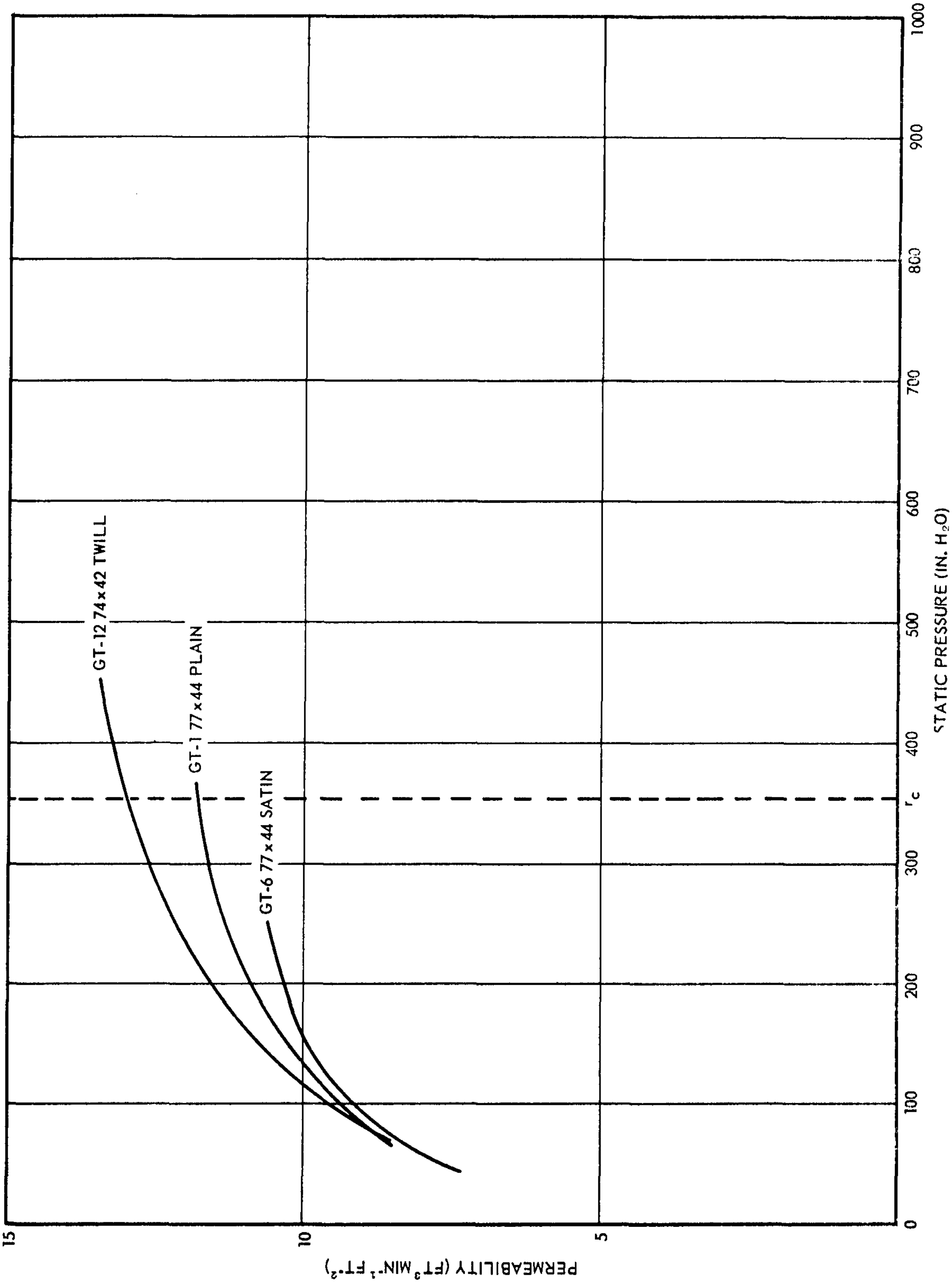

Figure 18. Effect of Weave Variation on Air Permeability of 70/70 Denier Nylon Cloth.

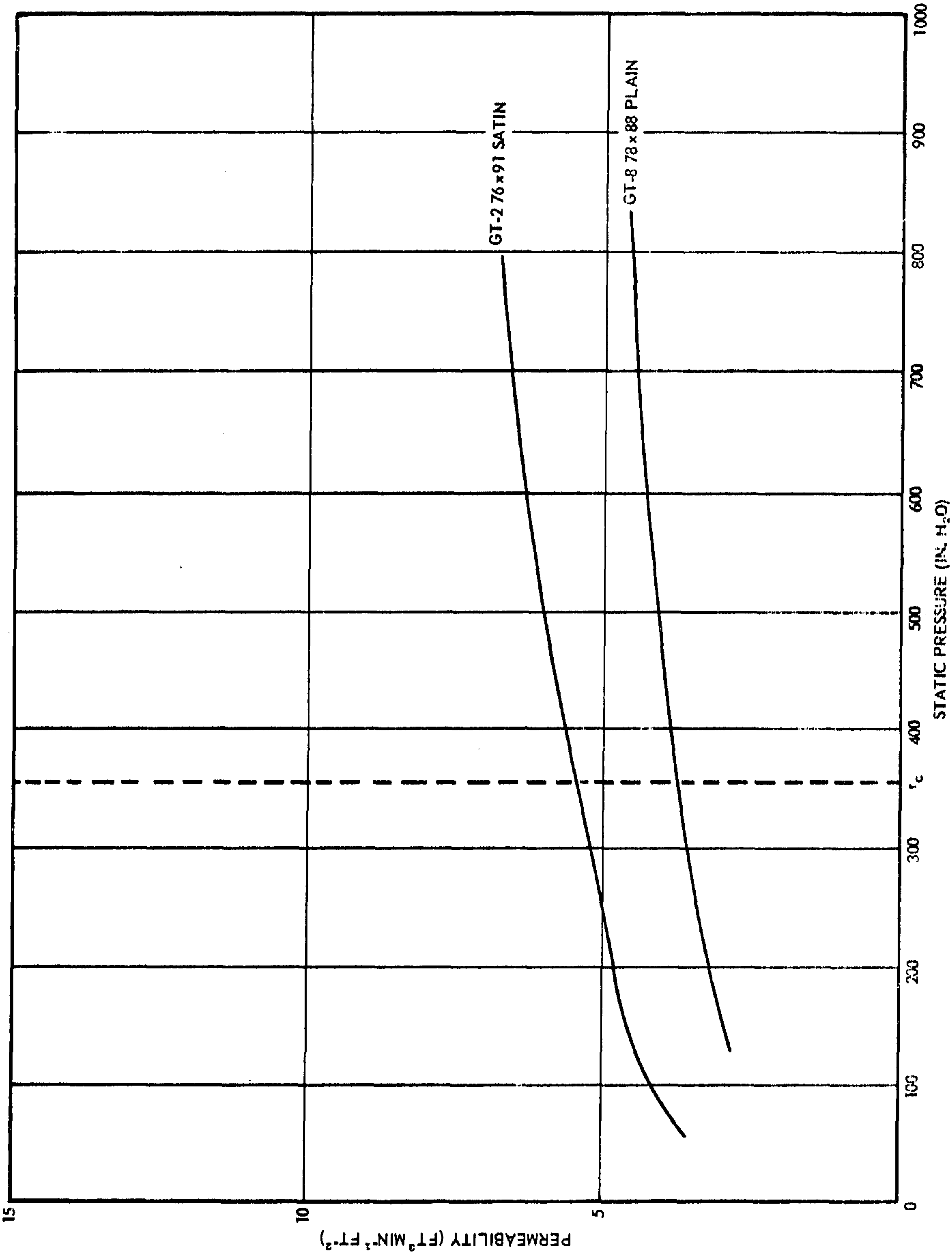

Figure 19. Effect of Weave Variation on Air Permeability of 70/70 Denier Nylon Cloth.

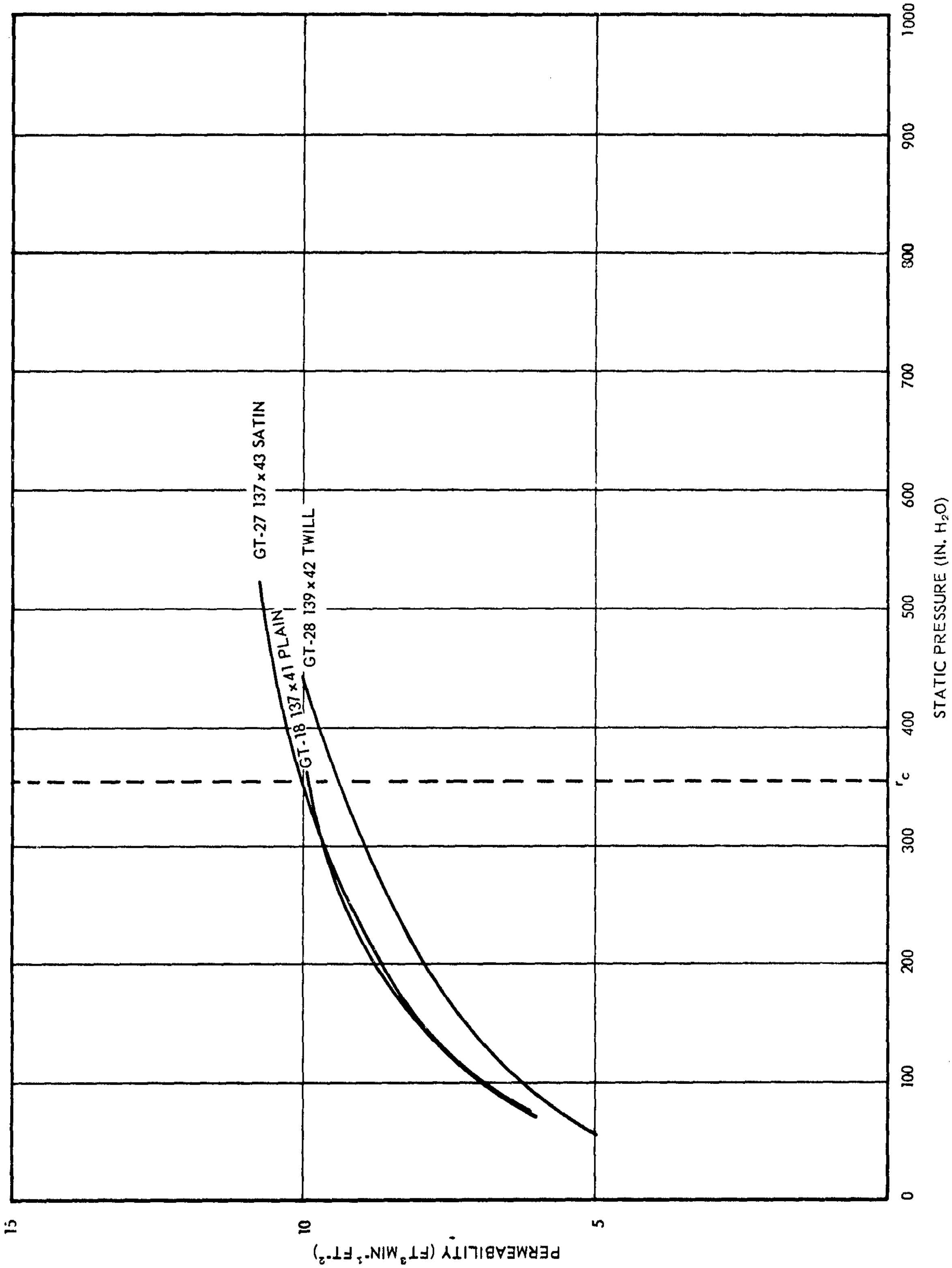

Figure 20. Effect of Weave Variation on Air Permeability of 40/70 Denier Nylon Cloth.

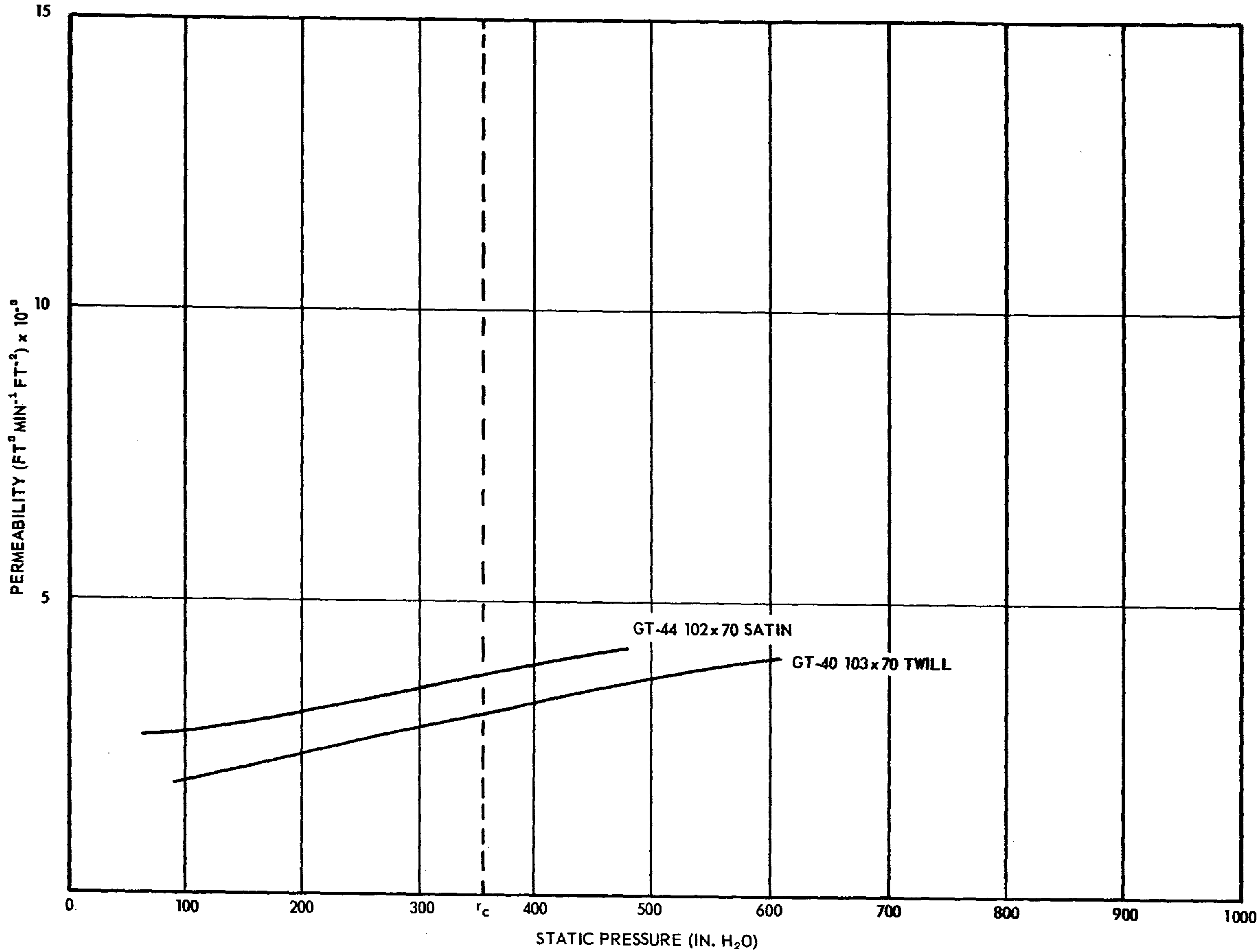

Figure 21. Effect of Weave Variation on Air Permeability of 75/75 Denier Orlon Cloth.

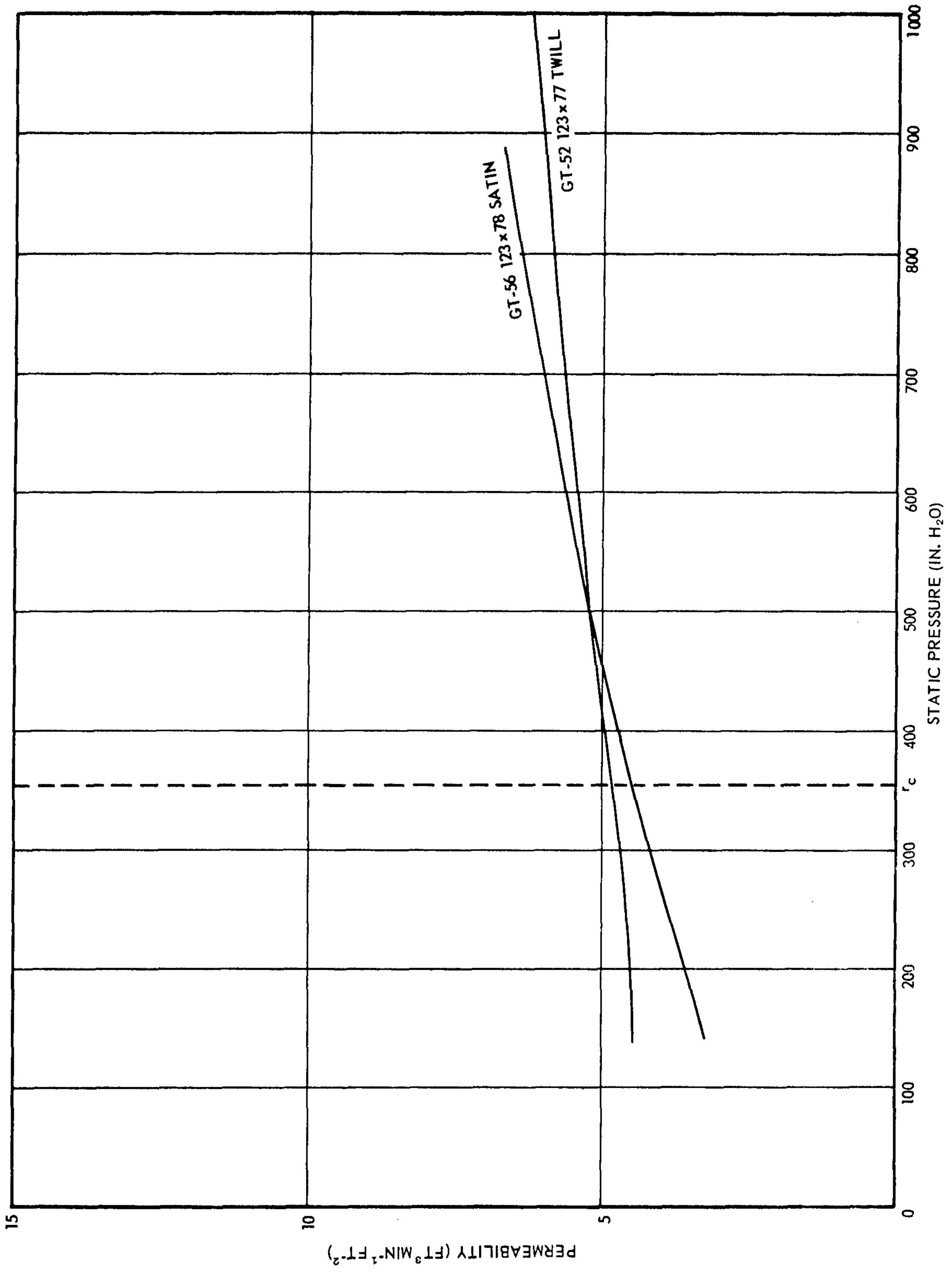

Figure 22. Effect of Weave Variation on Air Permeability of 70/70 Denier Dacron Cloth.

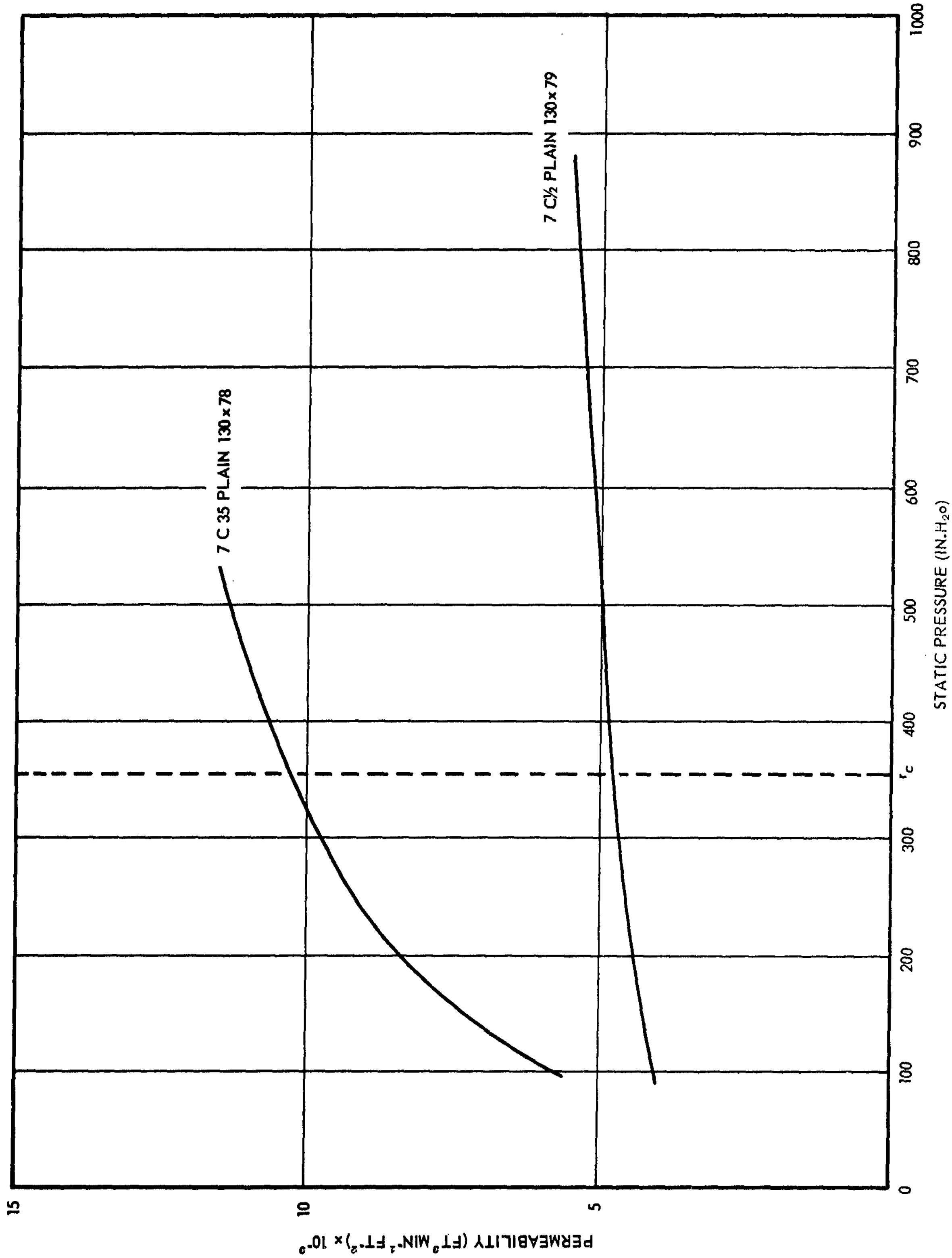

Figure 23. Effect of Twist on Air Permeability of 40/70 Denier Nylon Cloth.

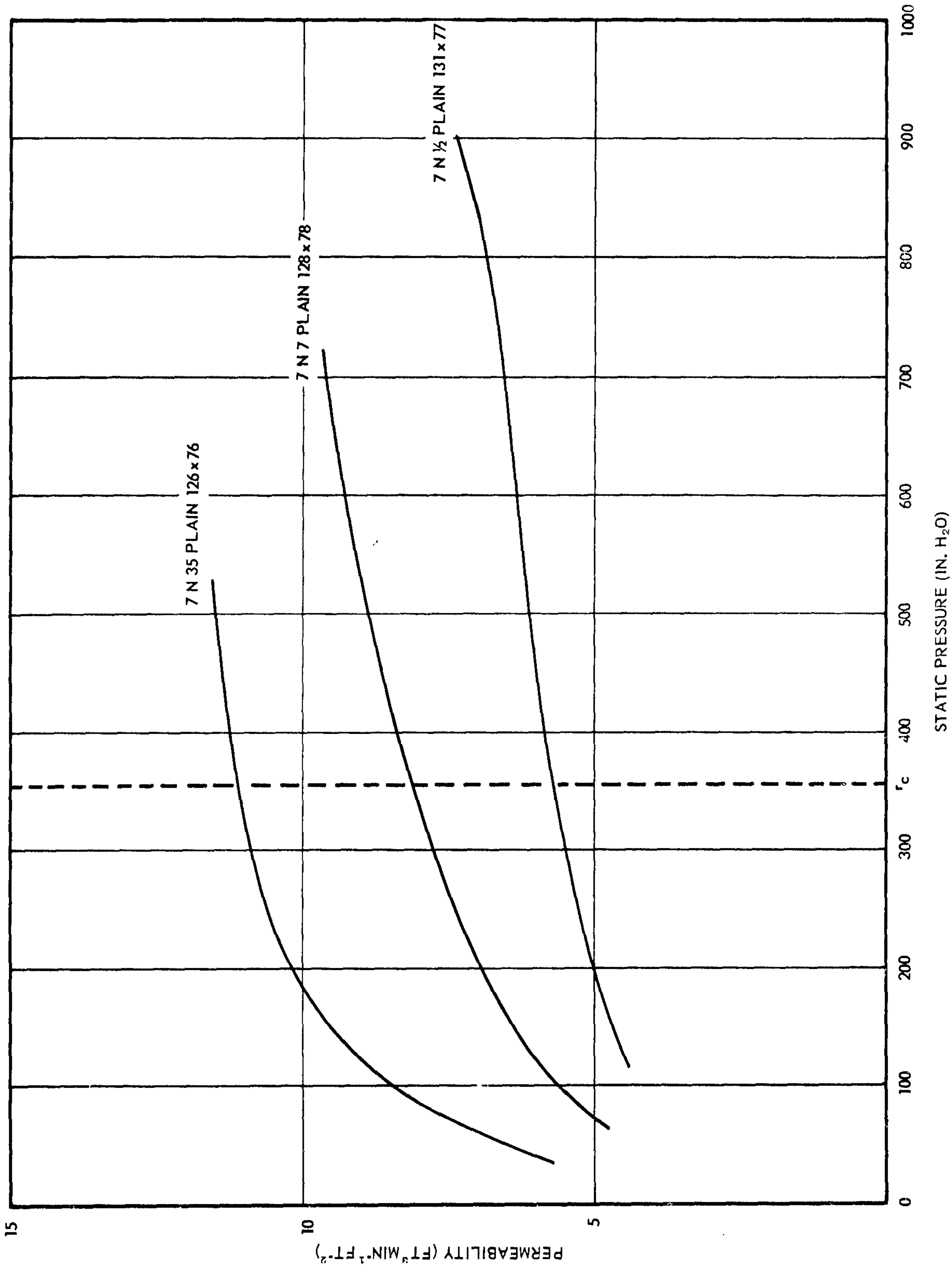

Figure 24. Effect of Twist on Air Permeability of 40/70 Denier Nylon Cloth.

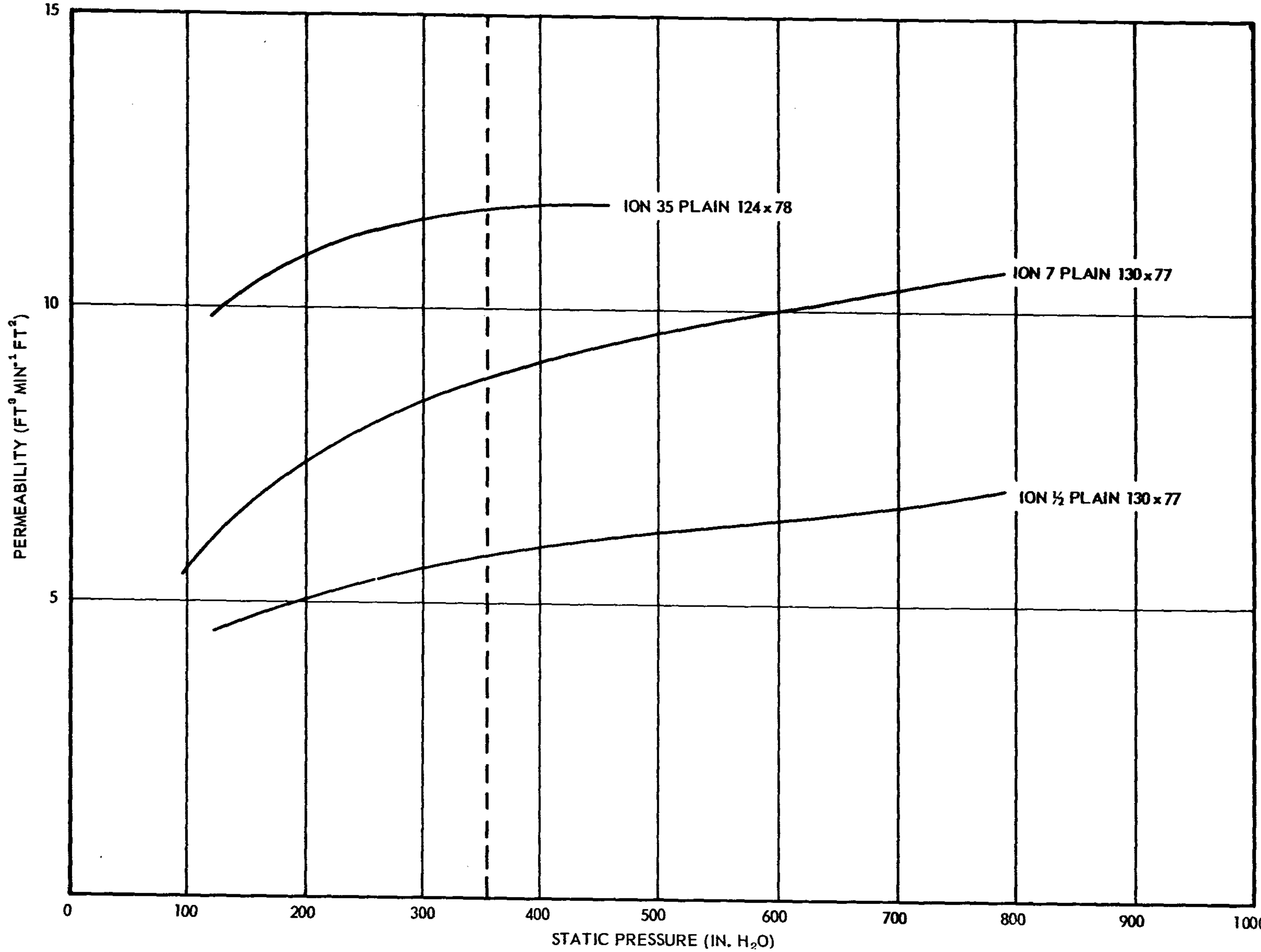

Figure 25. Effect of Twist on Air Permeability of 40/70 Denier Nylon Cloth.

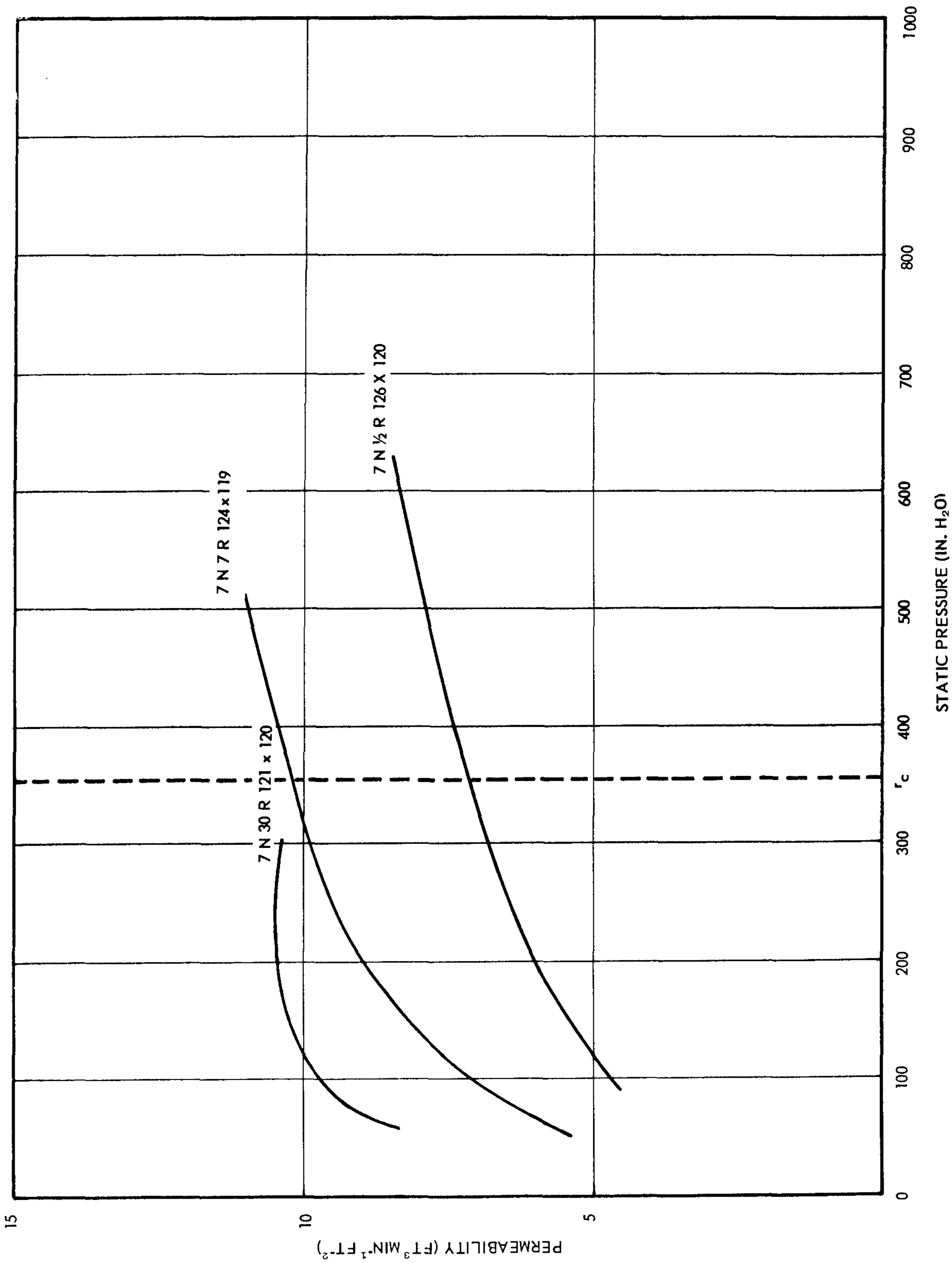

Figure 26. Effect of Twist on Air Permeability of 40/70 Denier Nylon Cloth.

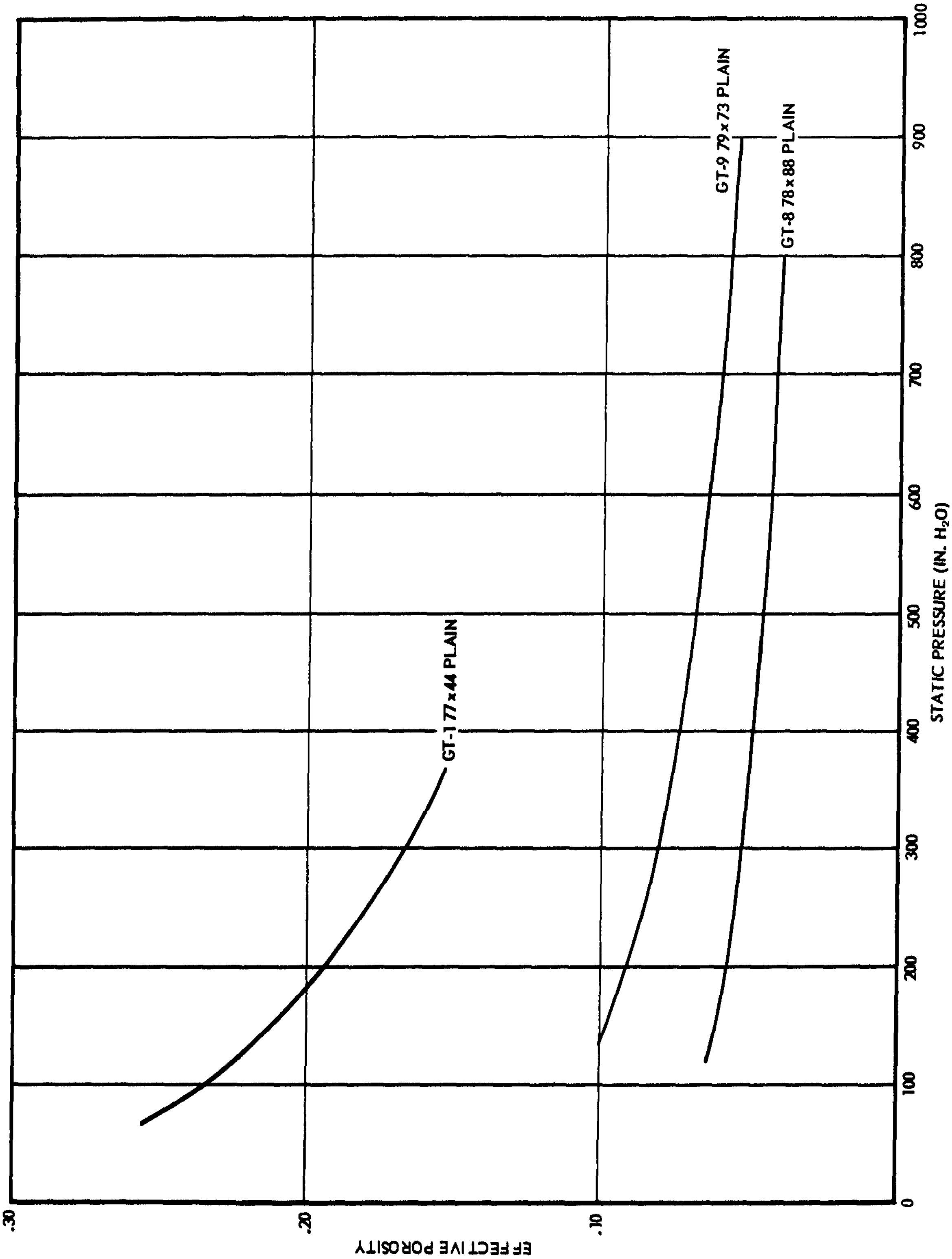

Figure 27. Effect of Pick Variation on Effective Porosity of 70/70 Denier Nylon Cloth.

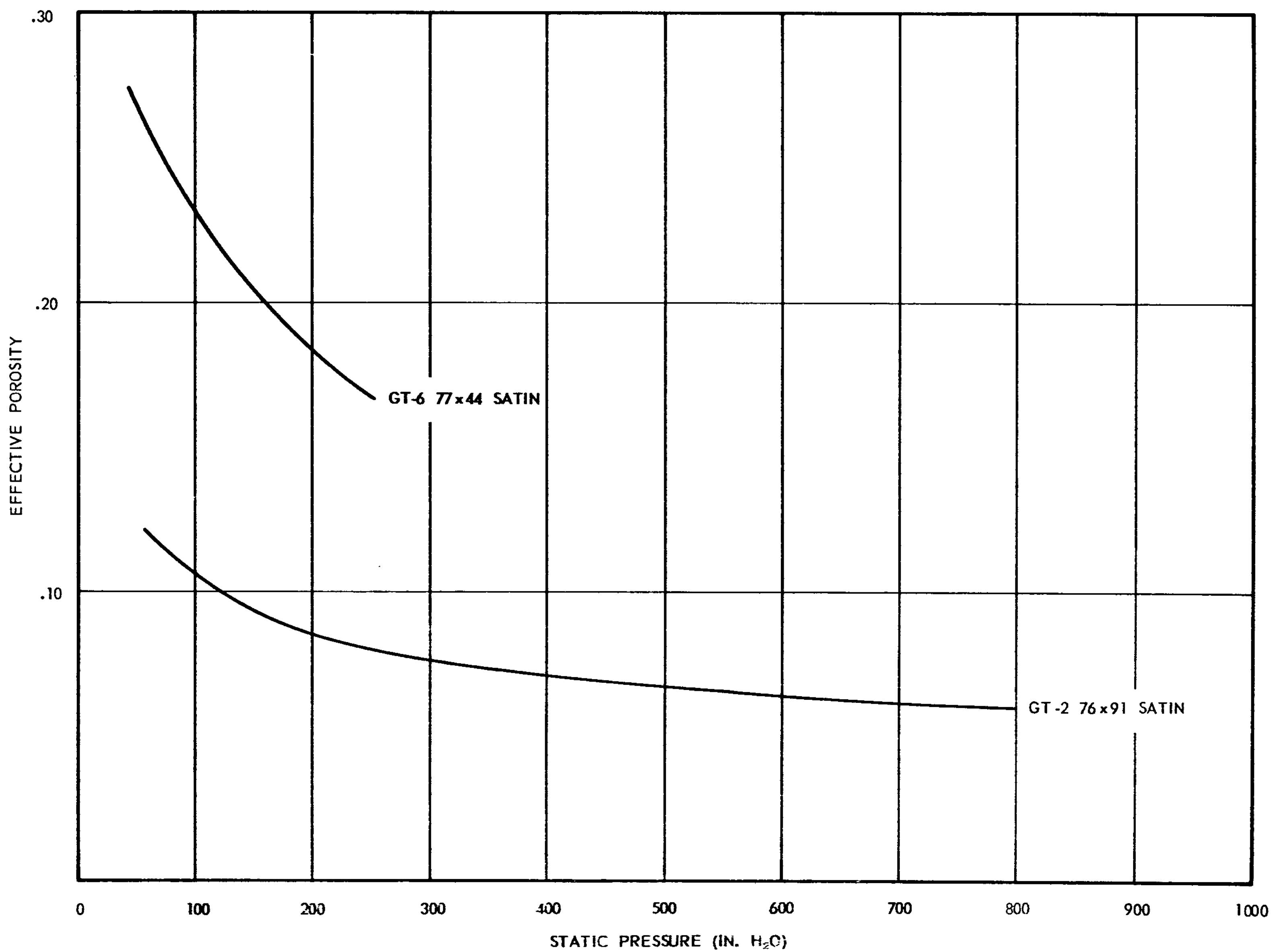

Figure 28. Effect of Pick Variation on Effective Porosity of 70/70 Denier Nylon Cloth.

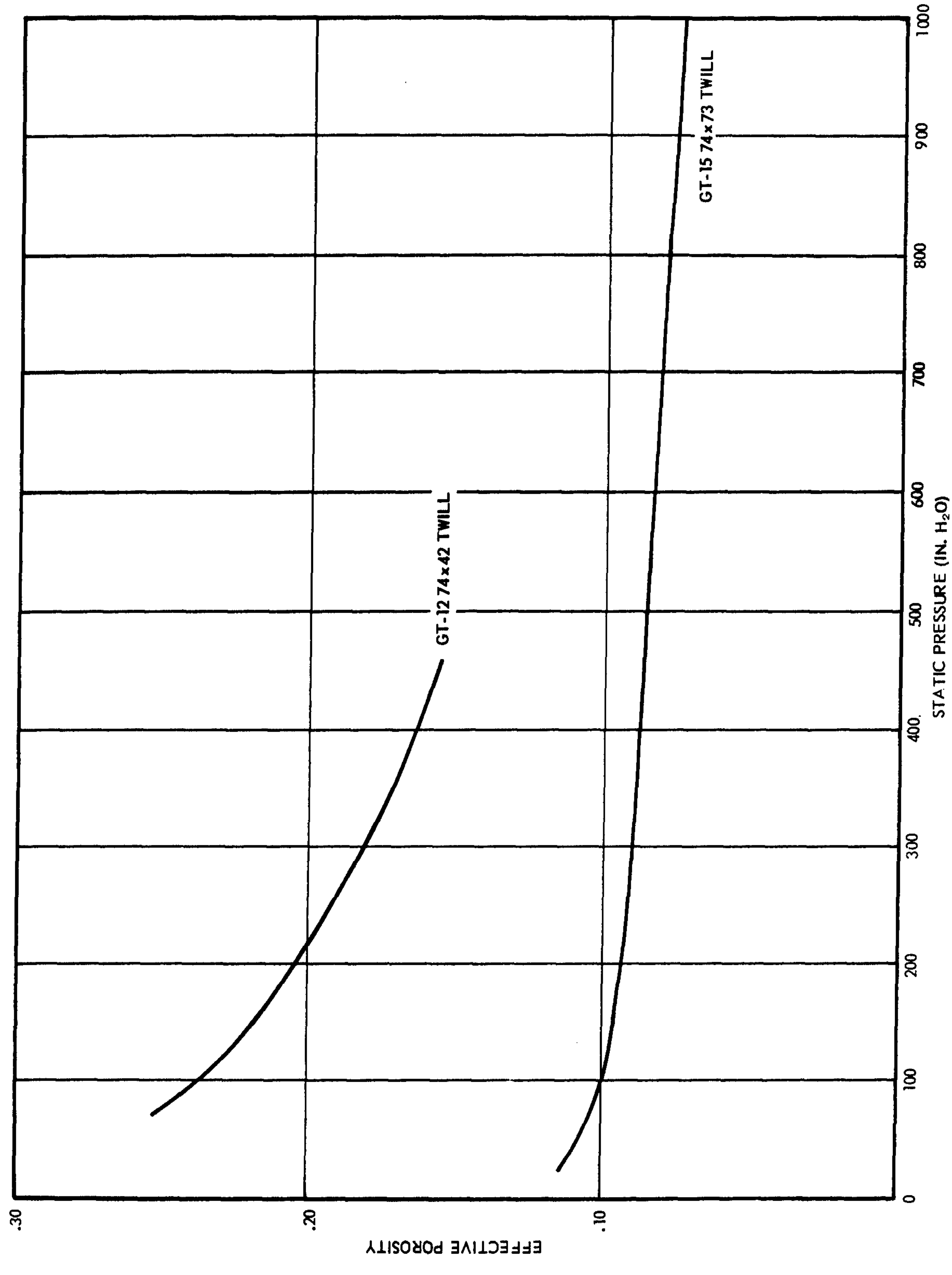

Figure 29. Effect of Pick Variation on Effective Porosity of 70/70 Denier Nylon Cloth.

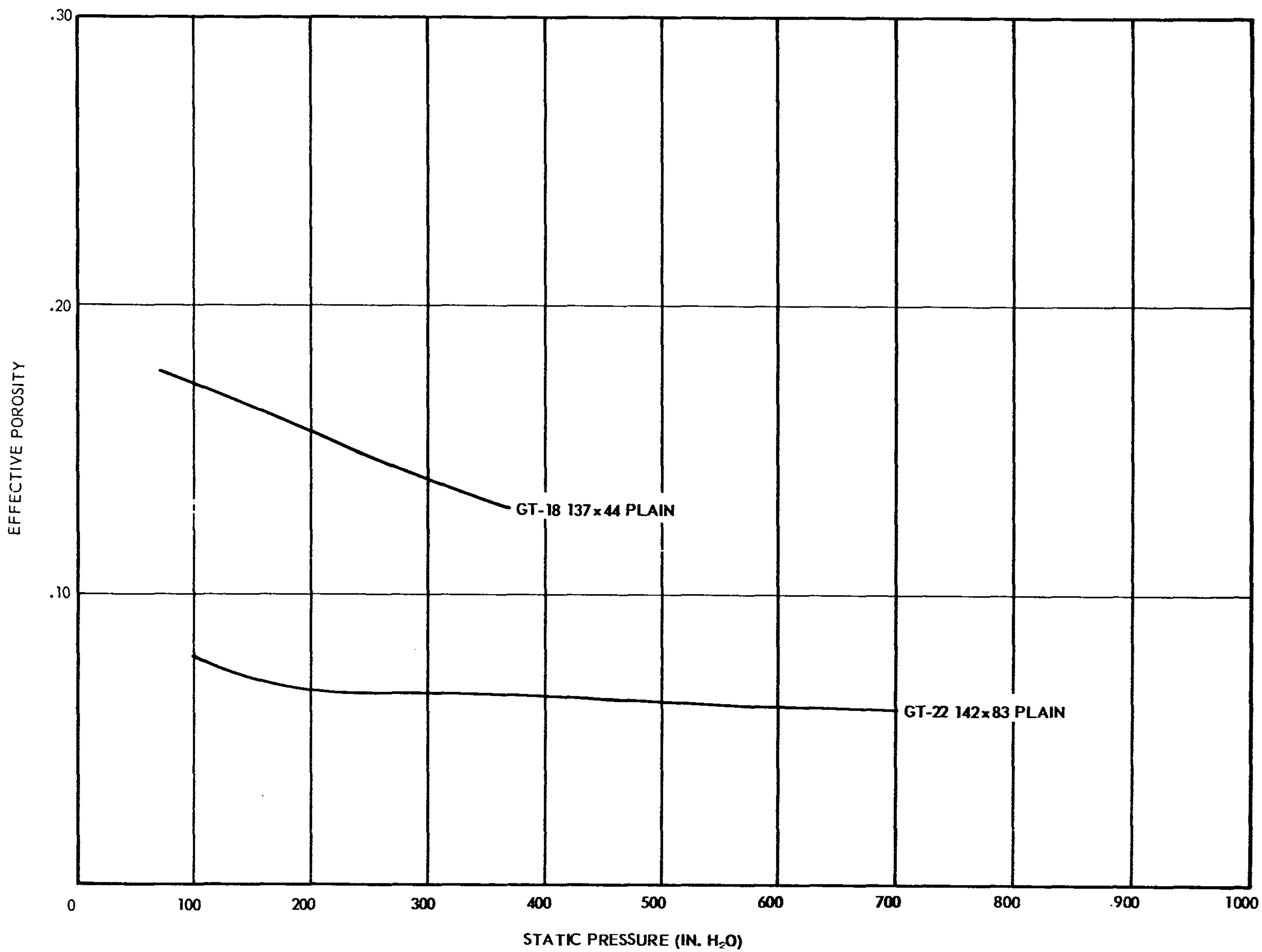

Figure 30. Effect of Pick Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

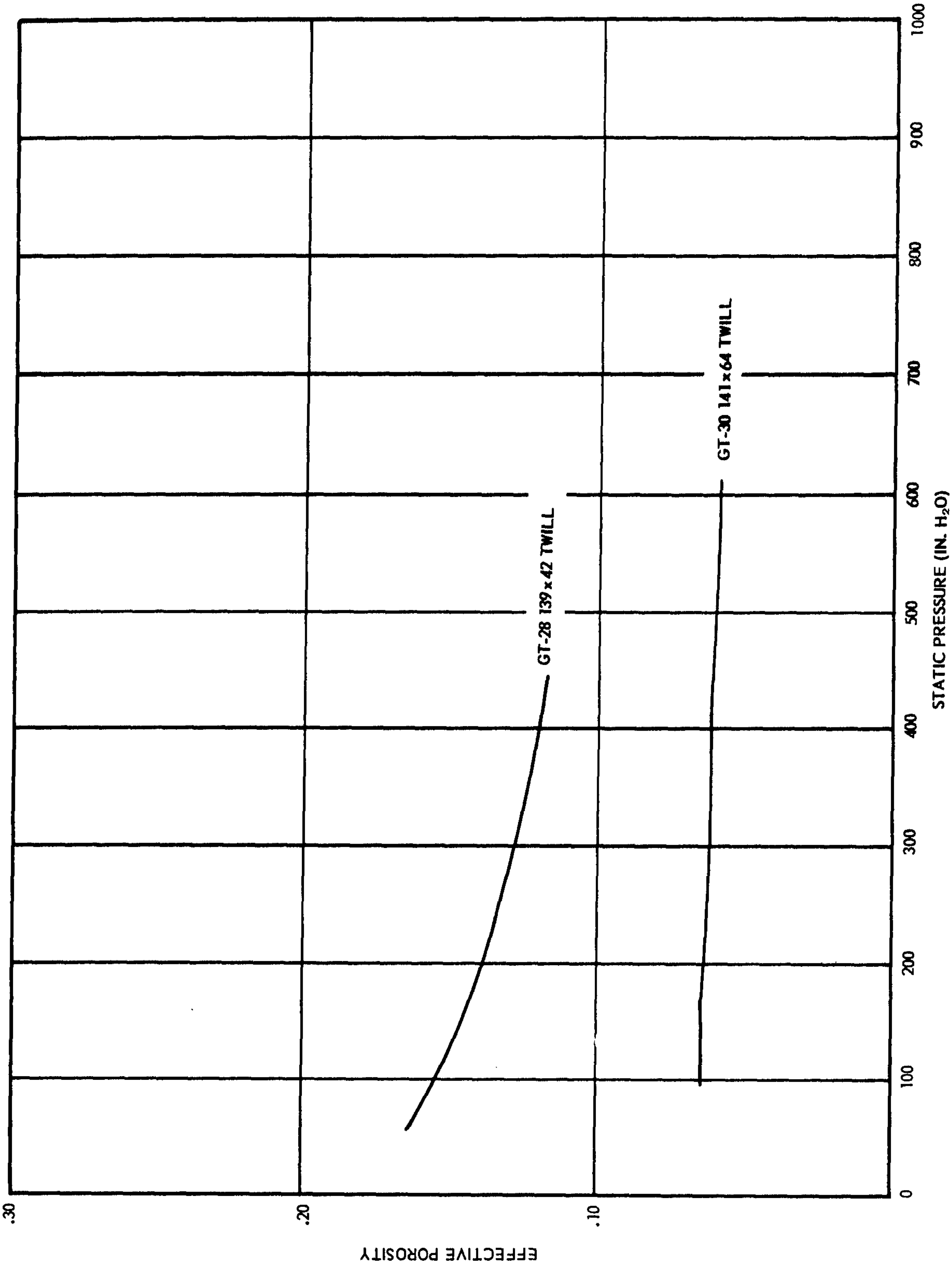

Figure 31. Effect of Pick Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

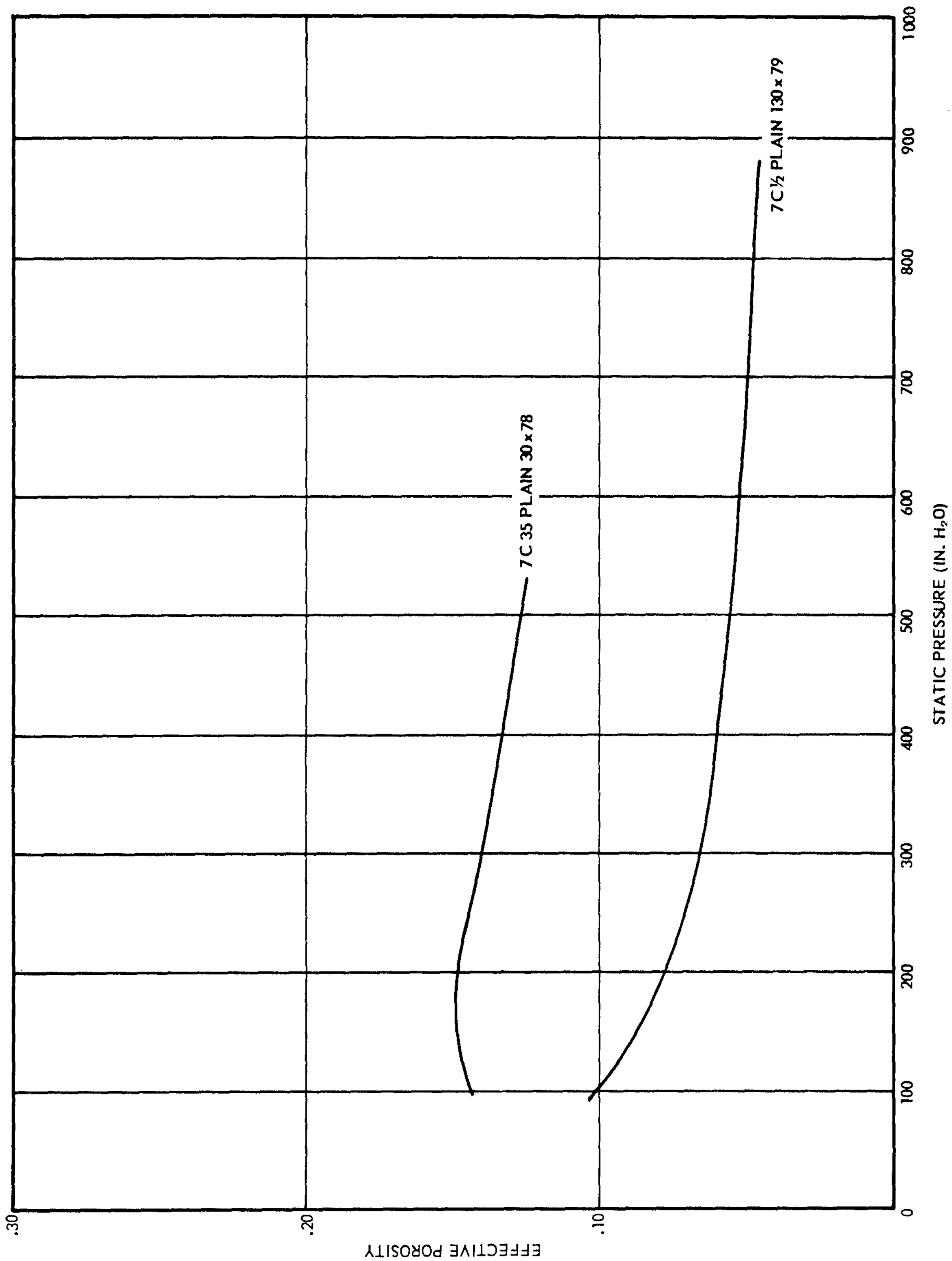

Figure 32. Effect of Twist Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

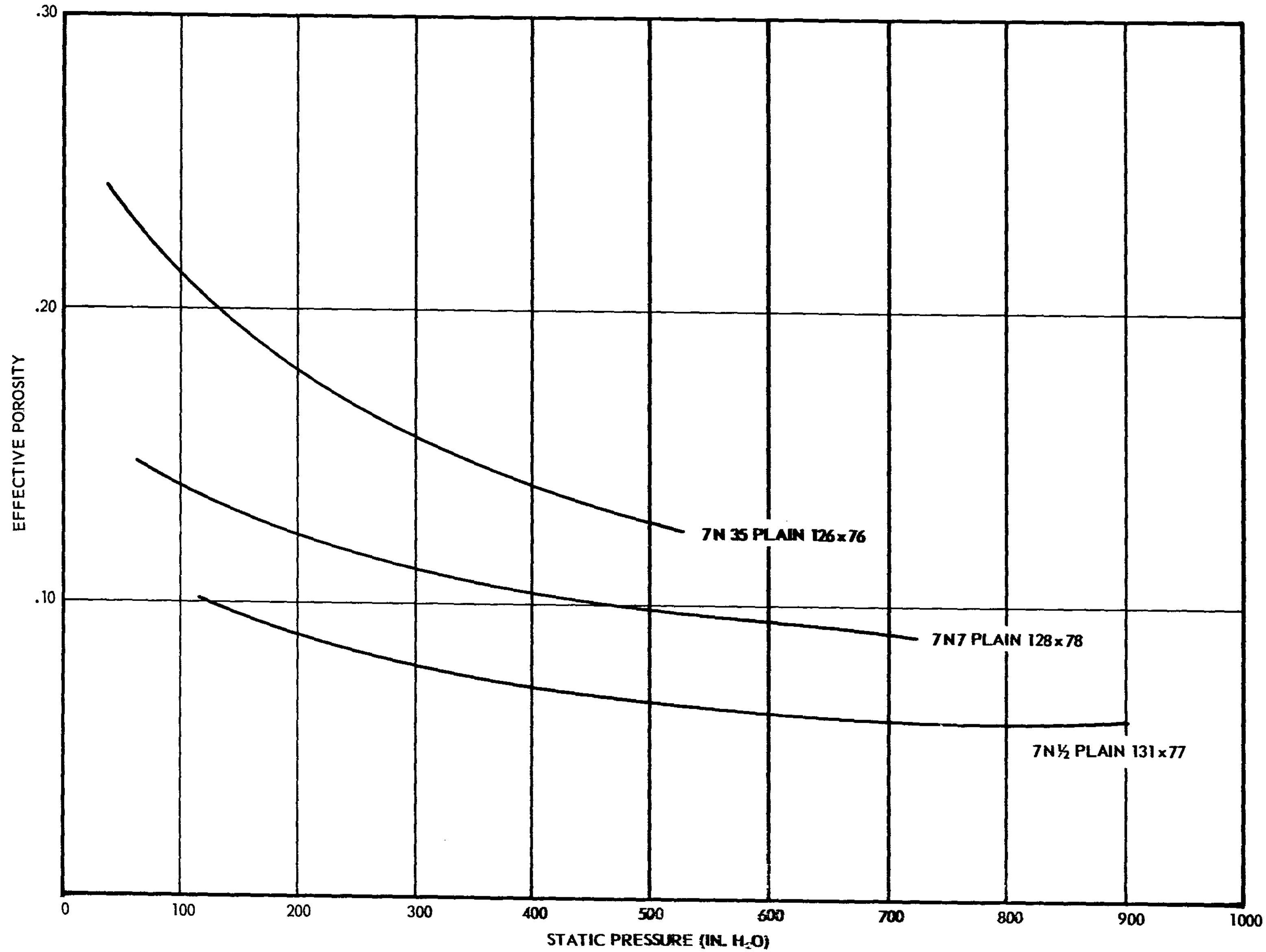

Figure 33. Effect of Twist Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

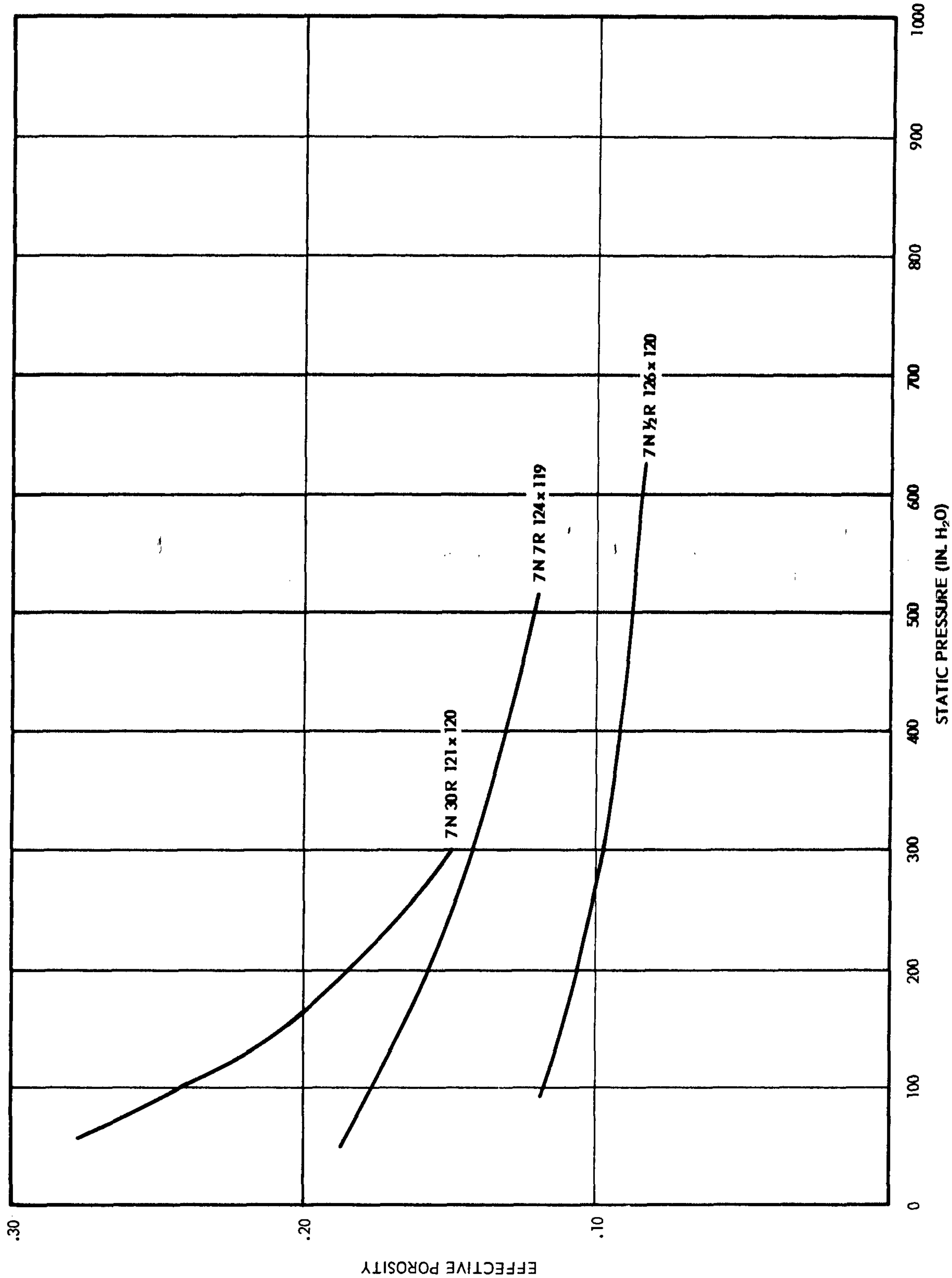

Figure 34. Effect of Twist Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

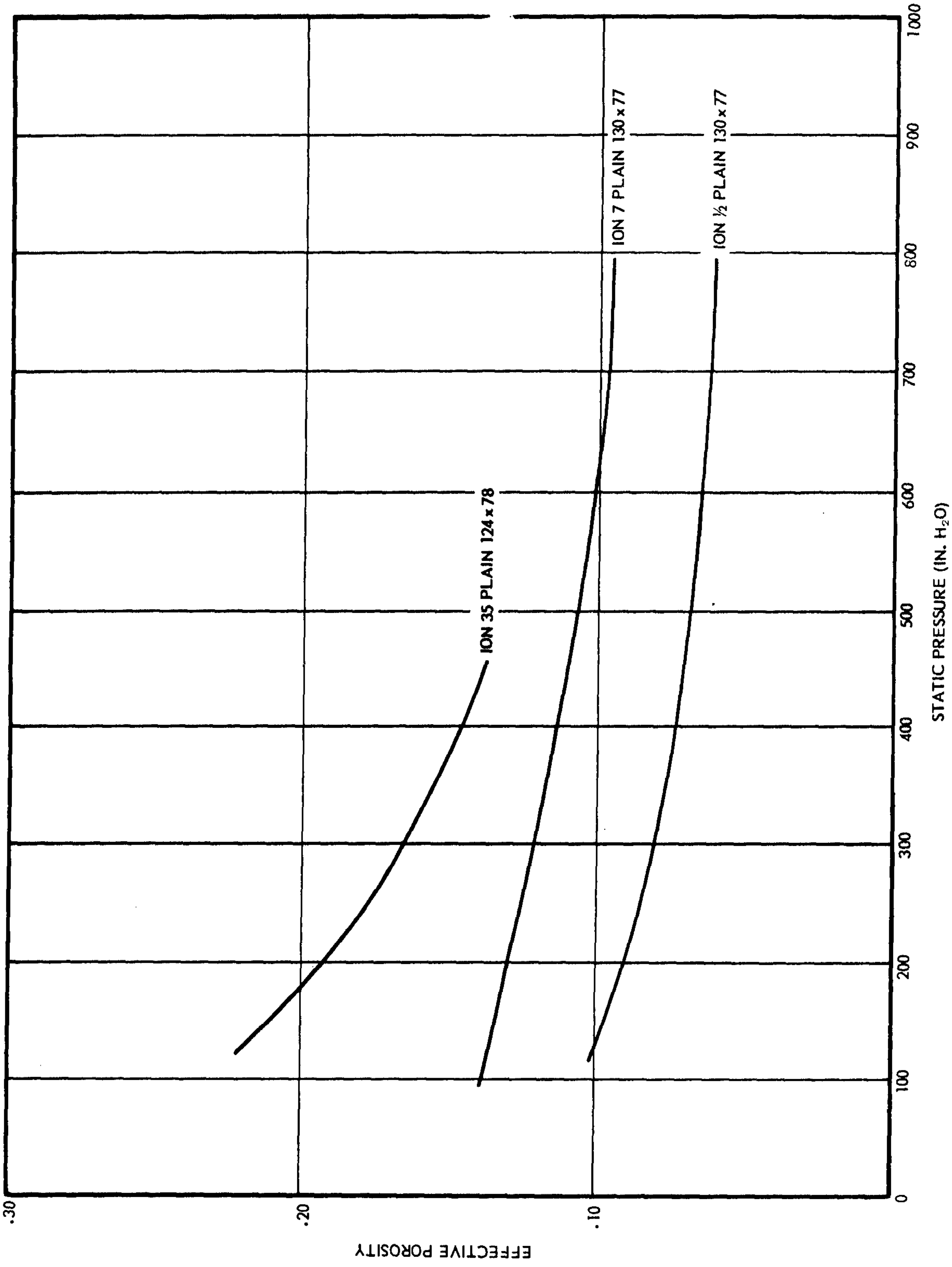

Figure 35. Effect of Twist Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

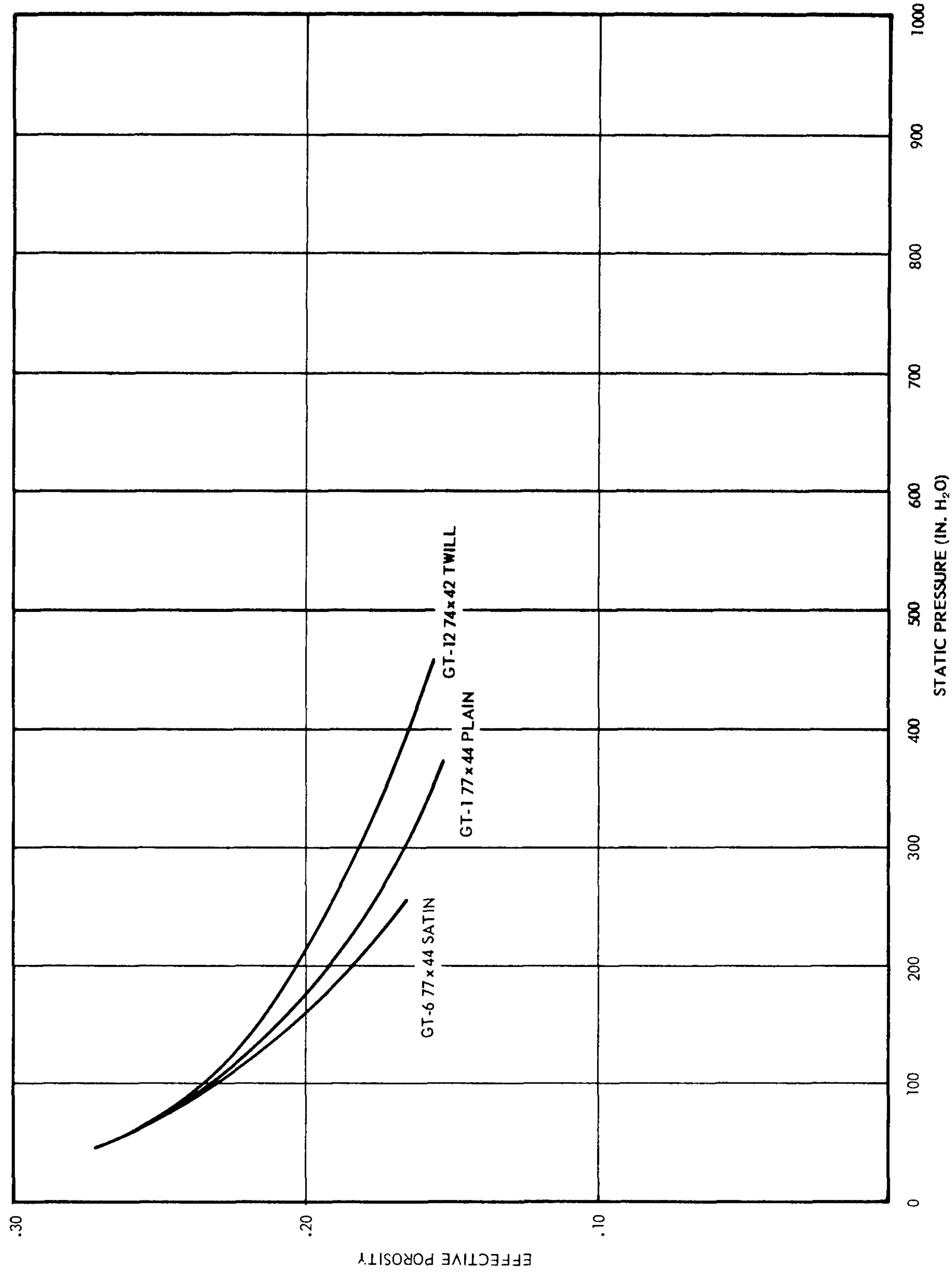

Figure 36. Effect of Weave Variation on Effective Porosity of 70/70 Denier Nylon Cloth.

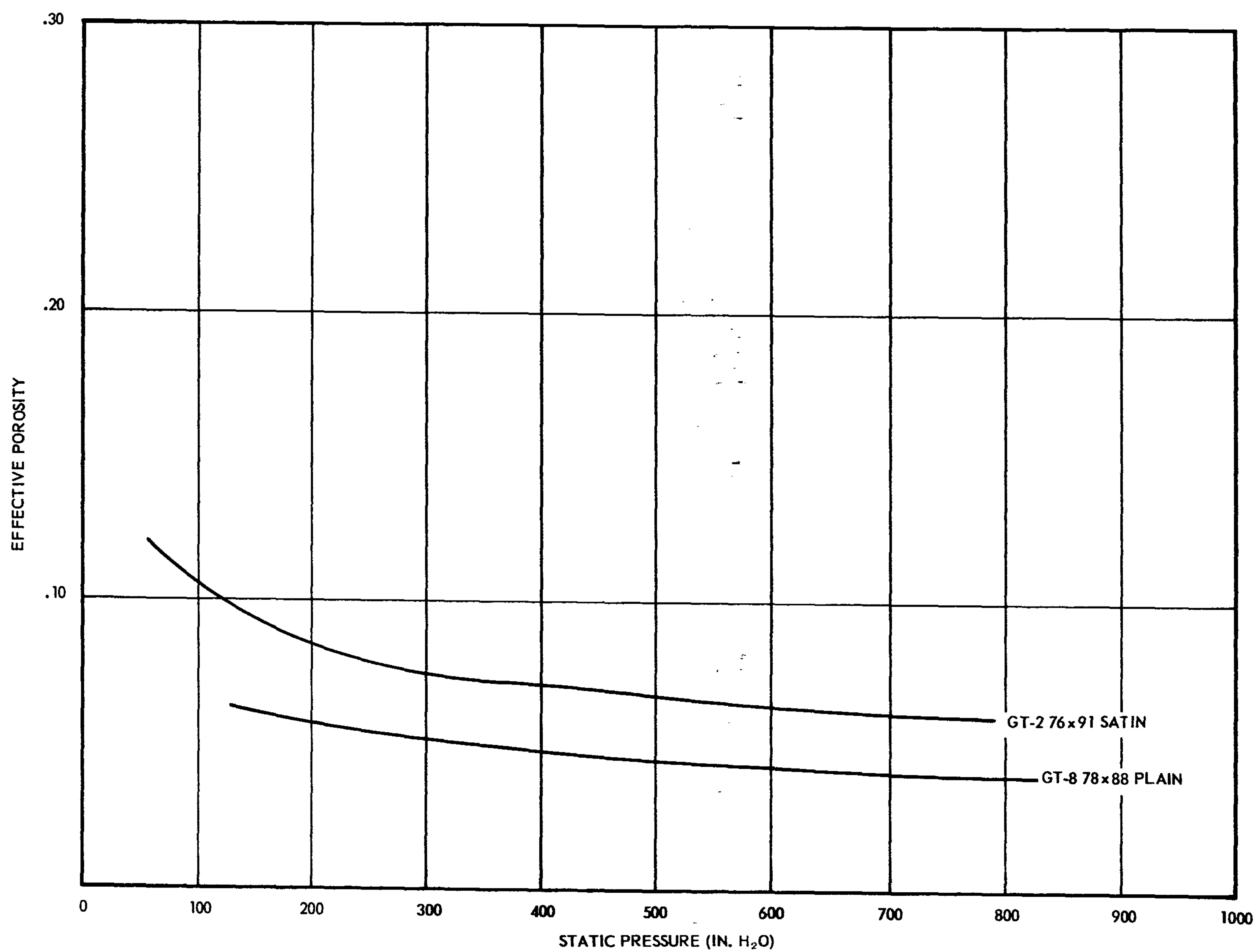

Figure 37. Effect of Weave Variation on Effective Porosity of 70/70 Denier Nylon Cloth.

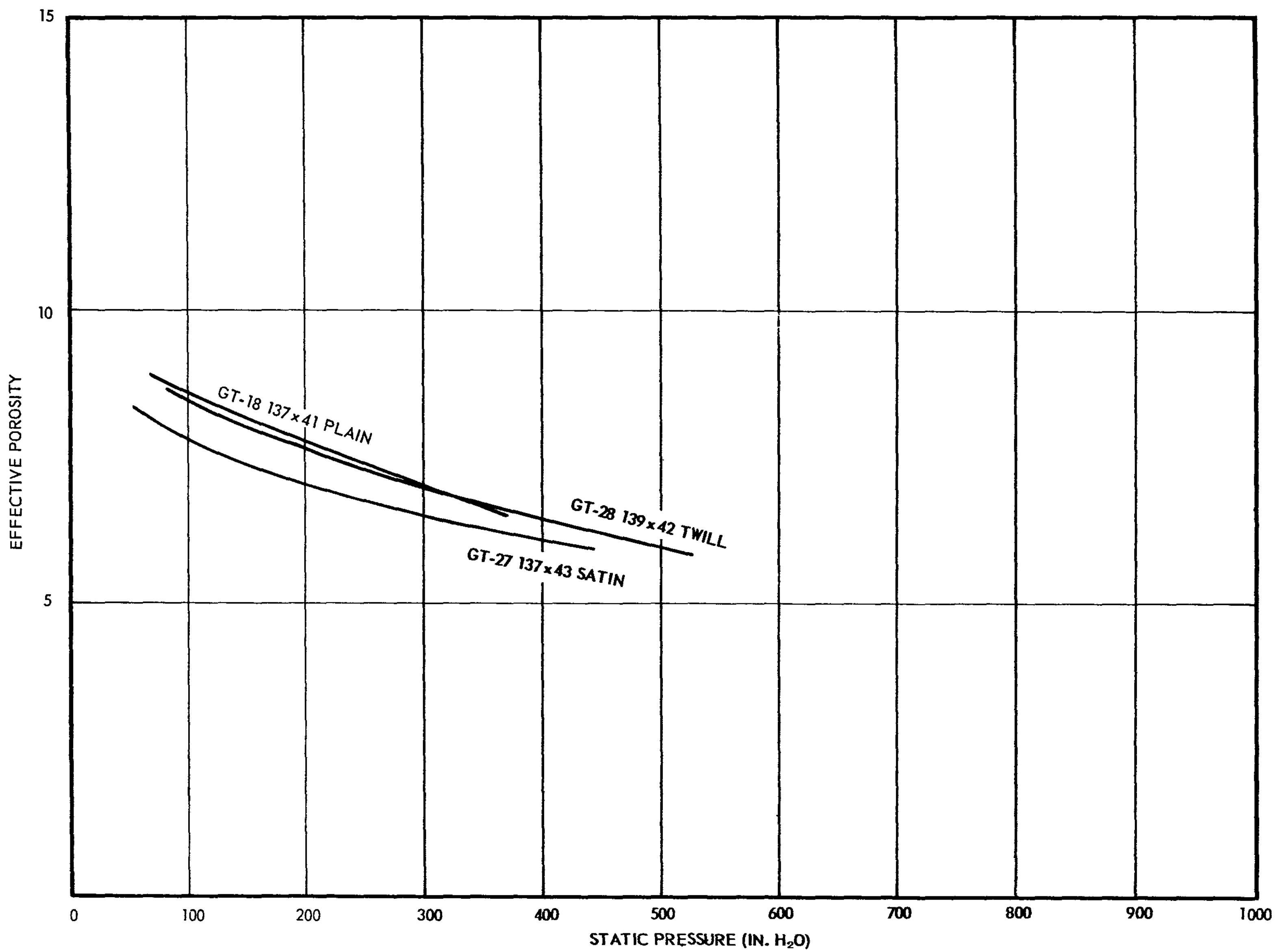

Figure 38. Effect of Weave Variation on Effective Porosity of 40/70 Denier Nylon Cloth.

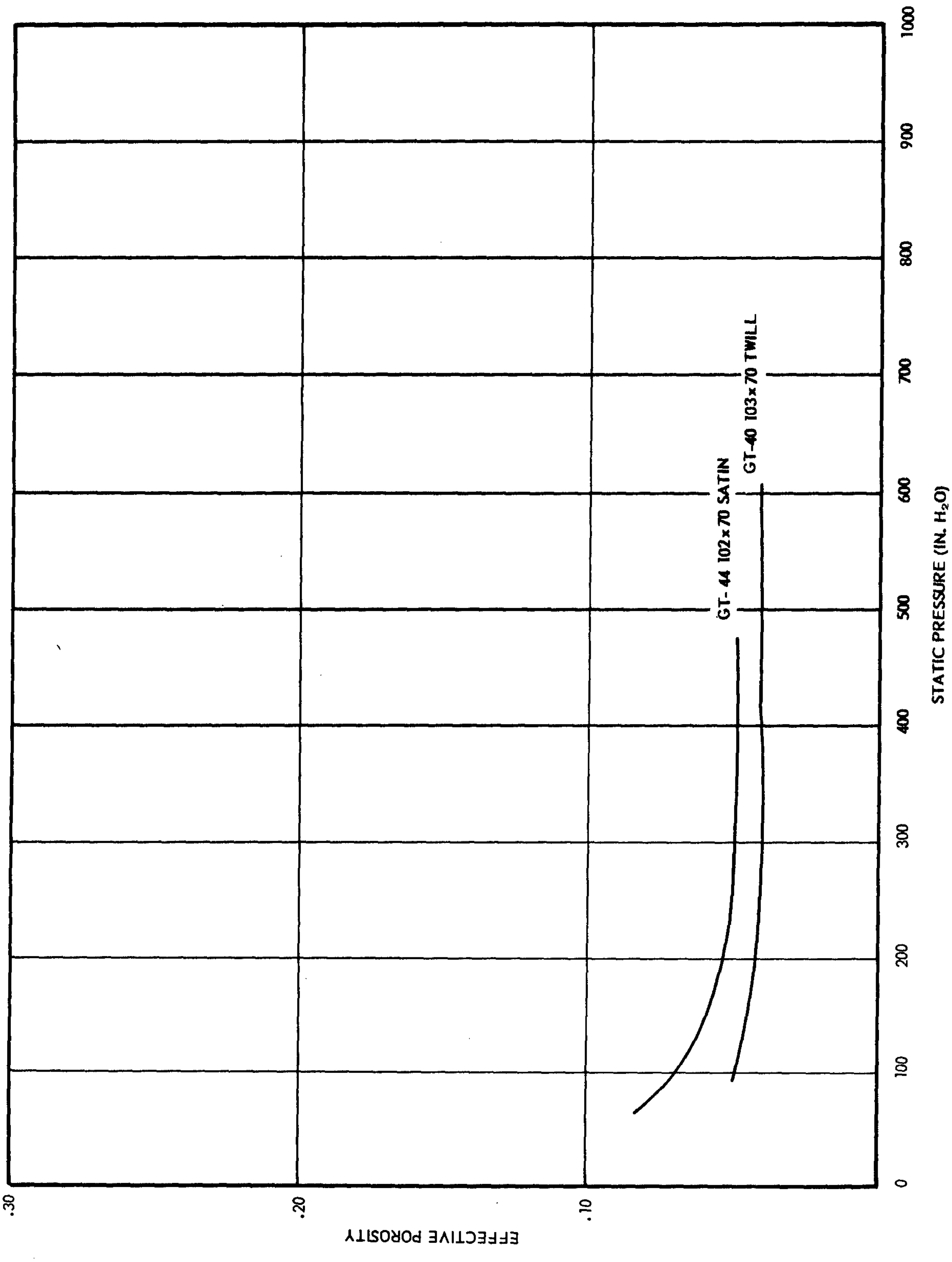

Figure 39. Effect of Weave Variation on Effective Porosity of 75/75 Denier Orlon Cloth.

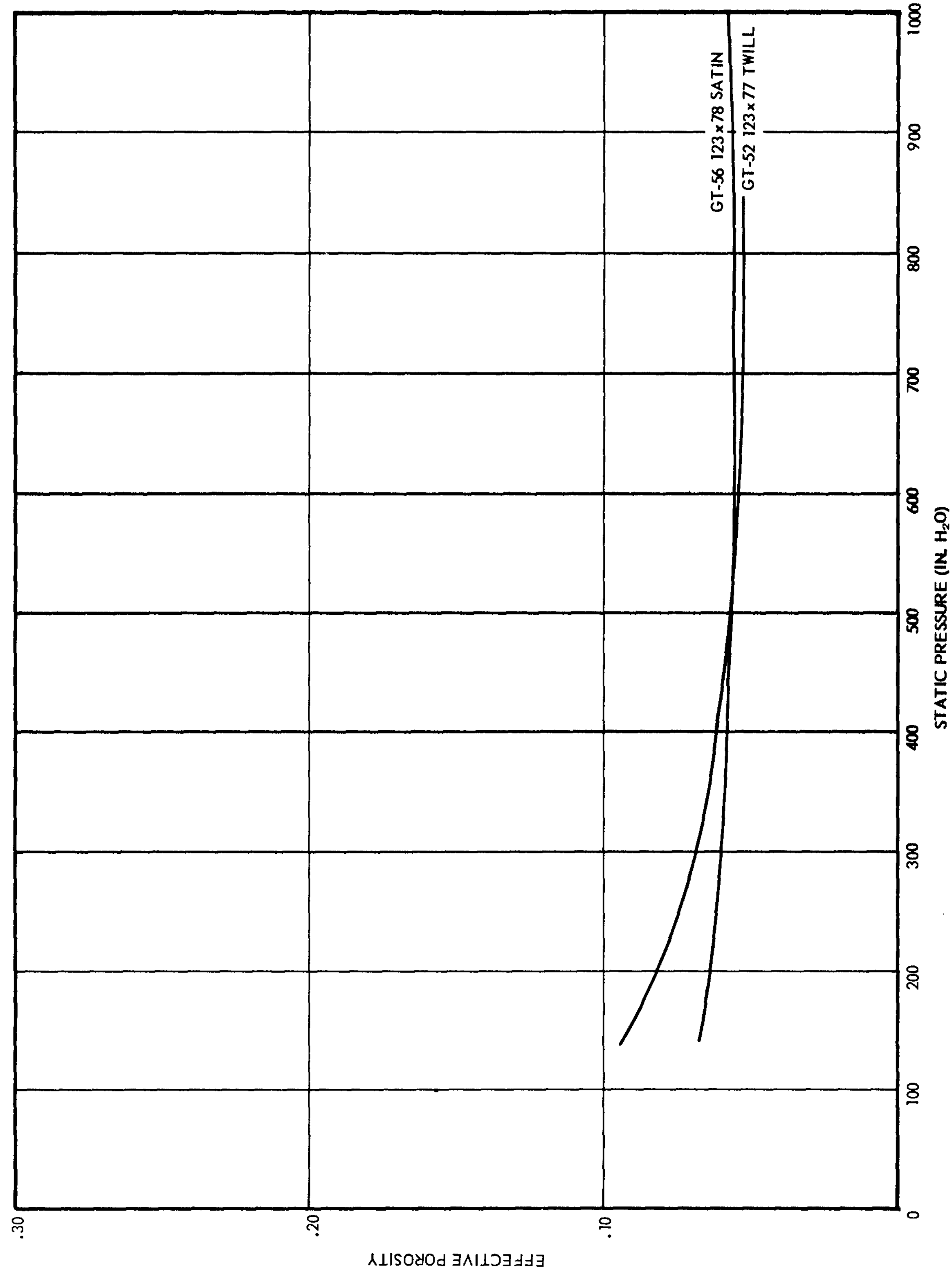

Figure 40. Effect of Weave Variation on Effective Porosity of 70/70 Denier Dacron Cloth.

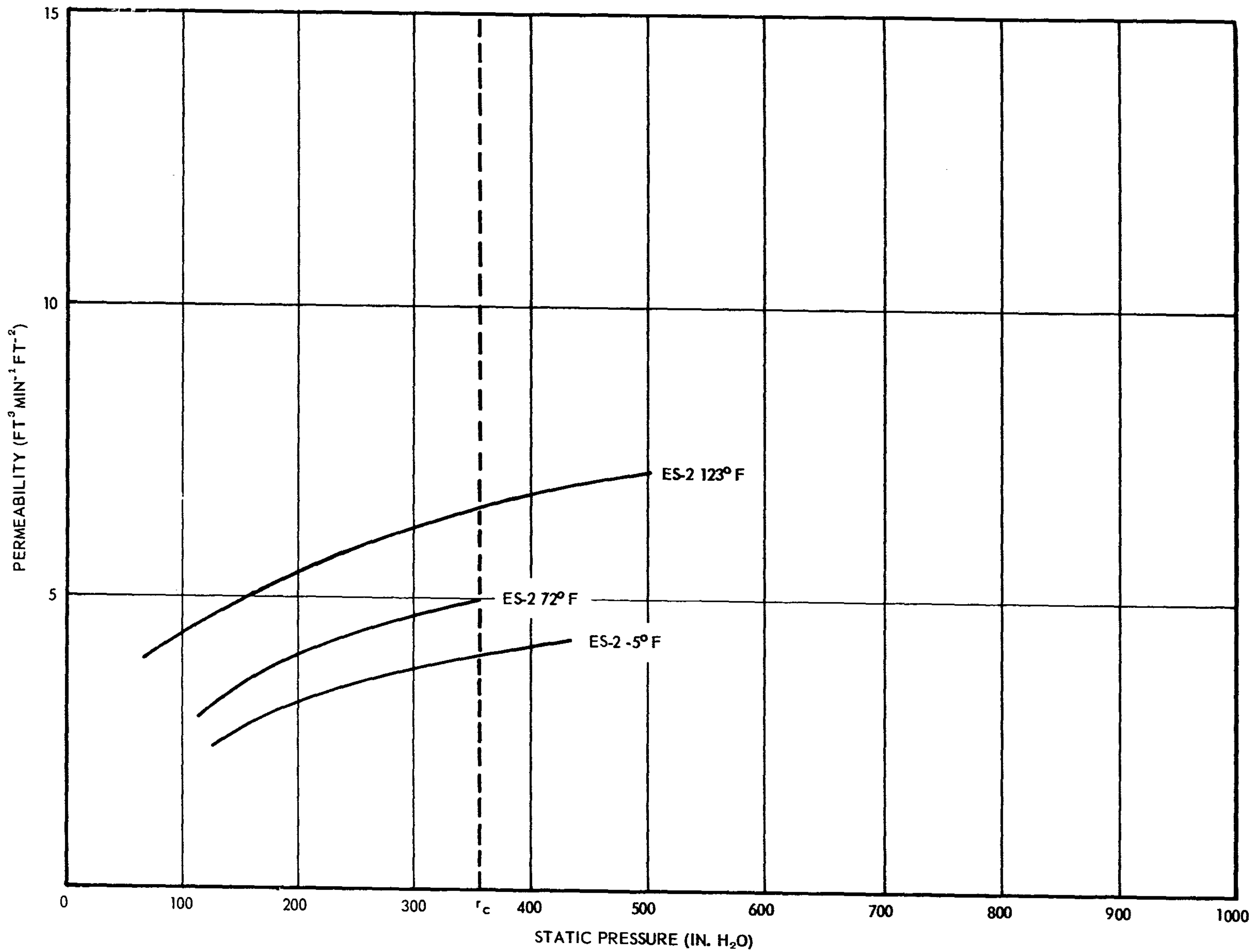

Figure 41. Effect of Variation of Air Temperature on Fabric Permeability.

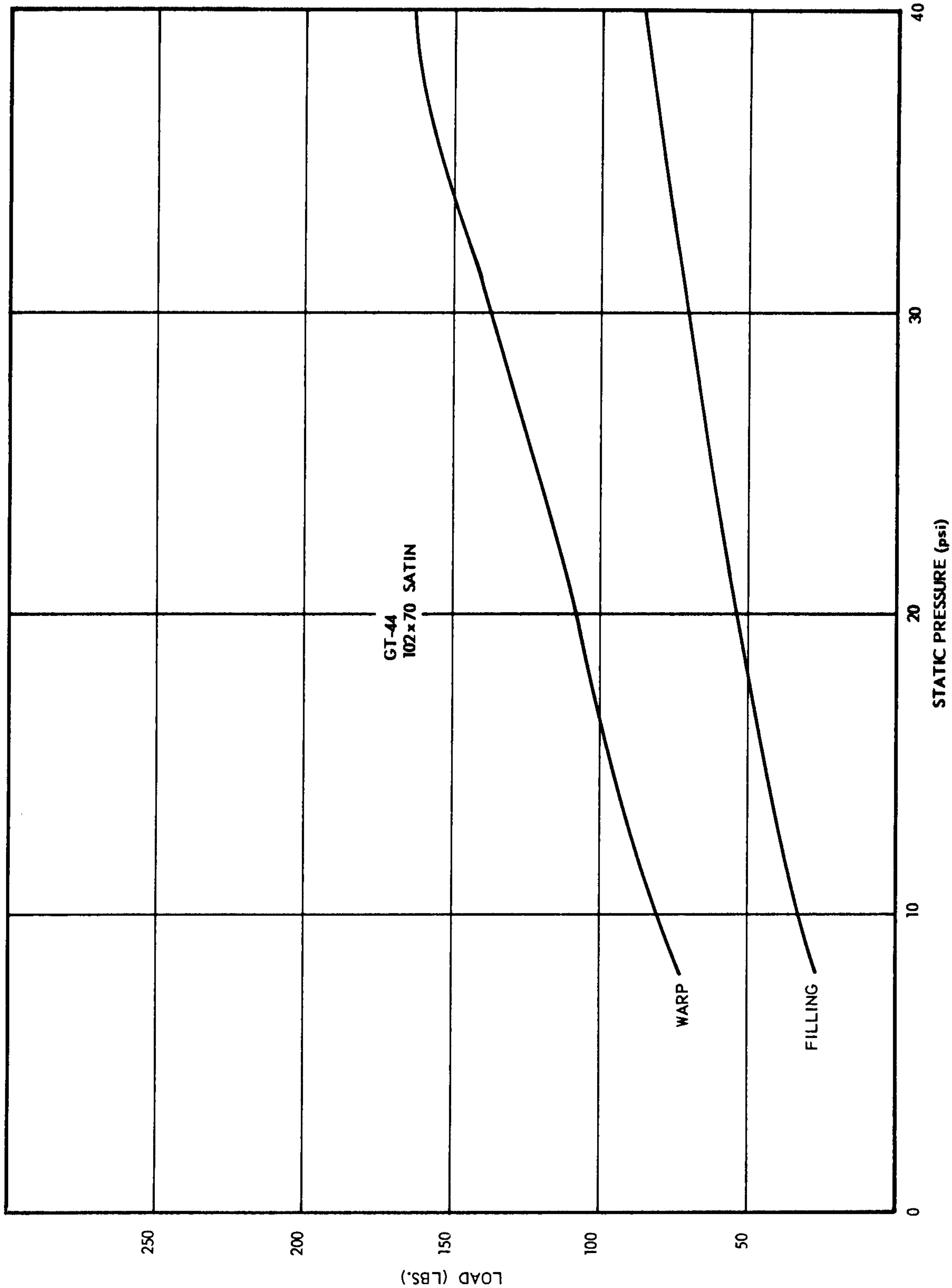

Figure 42. Variation of Load with Cloth Static Pressure.

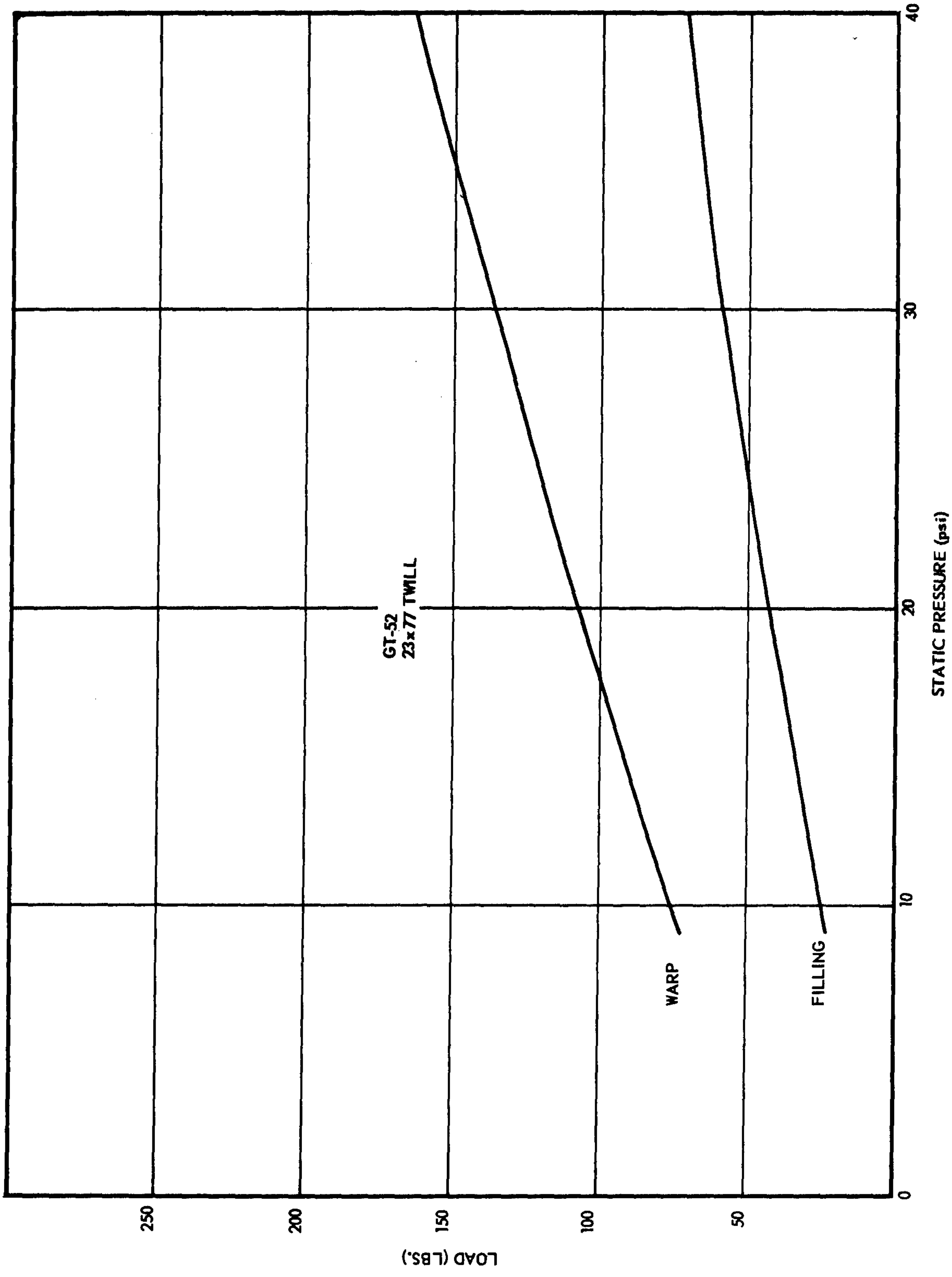

Figure 43. Variation of Load with Cloth Static Pressure.

ES-2: MIL-C-7020, Type, Orange Cloth

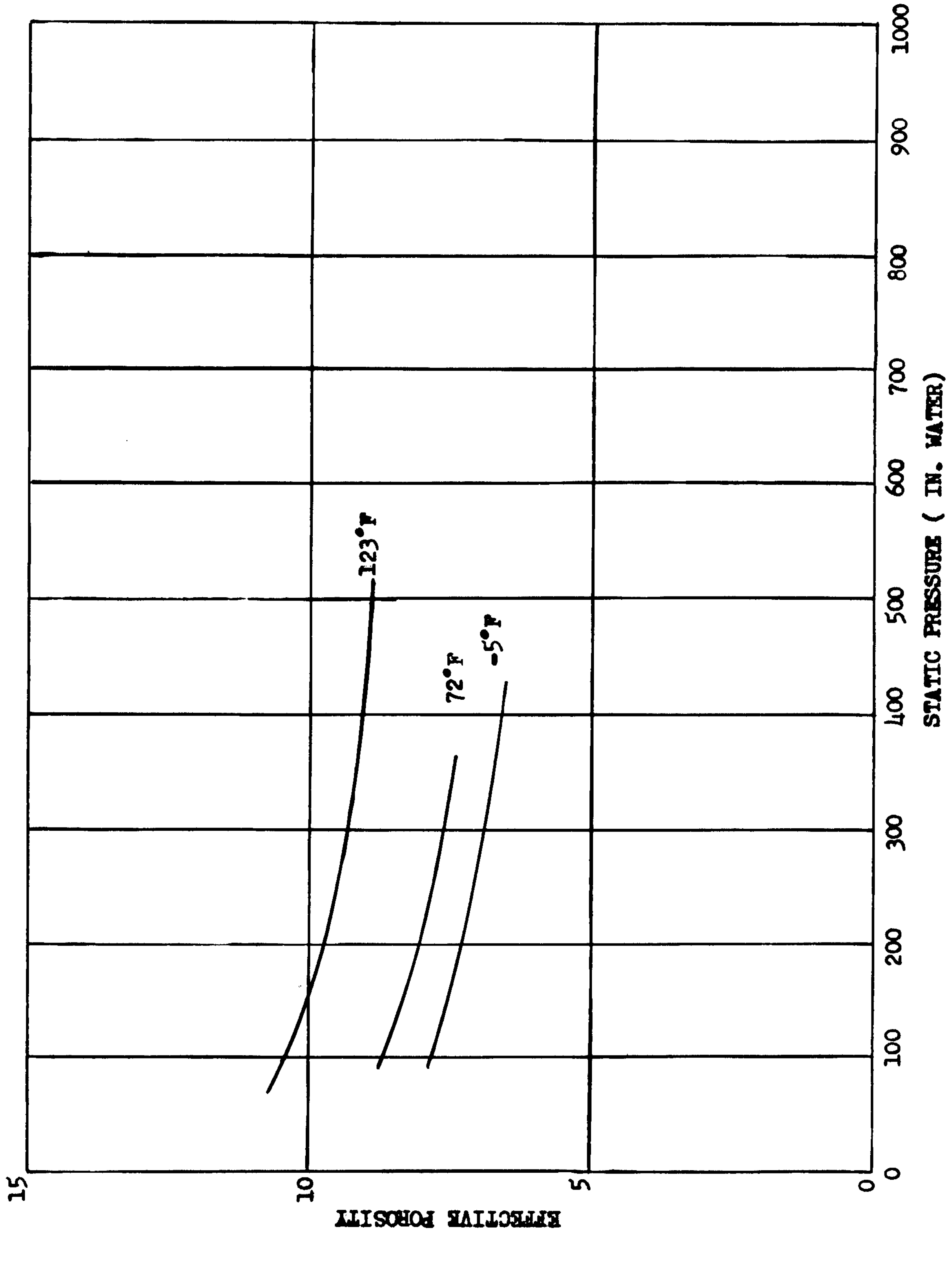

Figure 44. Effect of Temperature Variation on Fabric Porosity